STEPHEN K. CUSICK
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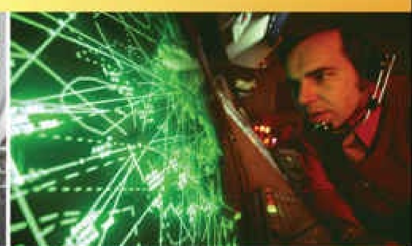
Commercial AVIATION SAFETY



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Mc Graw Hill Education

SIXTH EDITION

COMMERCIAL AVIATION SAFETY

Stephen K. Cusick
Antonio I. Cortés
Clarence C. Rodrigues

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PREFACE

It is not by luck and not by accident that our accident rates are what they are. Those were the words that kicked off a recent speech by the Associate Administrator of Aviation Safety of the Federal Aviation Administration. It has taken a century of hard work to make commercial aviation so wonderfully safe and an efficient means of transportation. On January 1, 1914, the first scheduled flight with a paying passenger took to the skies. Today, just over 100 years later, our skies are crisscrossed by contrails as over 50,000 aircraft fly through the airspace of the United States of America every day.

By the time you go to sleep tonight, almost two million passengers will have safely arrived at their destinations in the country. Safety depends on every single participant for continued success. Overall, commercial aviation is exceptionally safe, but the fight for safety must be waged, and won, every single day. The consequences otherwise are unacceptable. It takes the continuous dedication of hundreds of thousands of professionals, each hour of each day, to ensure the accident rate continues to be low.

In 2015 the passenger fatality rate was around one per 40 million, some four times better than the previous year, which was itself notoriously safe. In the Airline Safety & Losses review, Flightglobal’s Ascent consultancy arm showed eight fatal accidents in 2015, all pertaining to relatively small air carriers and with only three of the accidents entailing revenue passenger flights. Not a single passenger fatality due to an accident was incurred on a Western-built jet, which is quite heartening considering that 32 million flights on such aircraft carried 3.7 billion passengers during that year. As stated by Flightglobal, “If the improvement on air safety since 2010 is maintained for the rest of the current decade, it will equate to some 4,000 fewer passenger and crew fatalities than during 2000–2009.”

This text provides a modern synthesis of the principles, industry practices, and regulatory requirements of commercial aviation safety in the United States and the global community and showcases emerging safety issues that will take center stage over the next dozen or so years. This book exposes the major tools in the safety toolkit and how all the tools work together to ensure that accident rates stay low and even continue to improve.

rates stay low and even continue to improve.

This edition has undergone a significant restructuring to enhance the logical flow of information and to update the content. The revised flow starts with fundamental concepts of aviation safety, then explores the roles of humans in both causing and preventing accidents, showcases the ingenious approaches used by today's safety professionals for managing risk, expounds on the key roles played by system designs, ties all the concepts together under the construct of a Safety Management System (SMS), and finishes with a preview of new or recently growing challenges, such as the threat of lasers, unmanned aerial systems (UAS), and software bugs.

The writing tone has been altered to make content more intuitive by introducing personal anecdotes and vivid examples. This edition also introduces coauthor Antonio Cortés, who is the Associate Dean of the College of Aviation at Embry-Riddle Aeronautical University in Daytona Beach, Florida. His experience as an airline pilot, aviation safety program manager, and human factors researcher add to the perspectives provided in this text.

Today's aviation professionals, be they airfield managers, dispatchers, insurance analysts, air traffic controllers, flight attendants, aviation maintenance technicians, or pilots, must understand how the key industry pieces fit together to produce the very safe world of air carrier operations that we enjoy today. A disruption to any part of the delicately woven safety net can jeopardize a century of work in aviation safety.

One aspect must be clarified before we go any further. What, exactly, do we mean by *commercial aviation safety*? For purposes of this text we are referring to the initiatives we put in place to prevent damaging or injuring events involving aircraft used to transport paying passengers or cargo. Those initiatives include procedures, automated warnings, personnel hiring and training, process analytics, scientific measures against fatigue, and countless other safeguards that are meticulously created to protect our loved ones and possessions as they transit through the air and operate on airports. Most of the content of the book focuses specifically on the airline, or air carrier, segments of commercial aviation.

FEATURES OF THE SIXTH EDITION

- Chapter 1 provides a high-level overview of commercial aviation safety. The chapter is new to the book and explains the link between safety and financial performance for commercial aviation ventures to include the distinction and complementary nature of aviation safety and occupational safety and health as

well as the differences and commonalities between safety and security. Basic philosophical principles of safety are included, as well as a brief coverage of safety history that includes key accidents that have shaped today's commercial aviation industry.

- Chapter 2 provides graspable answers to the complex question of why accidents happen. Accidents are explained as having deep roots that set up operators for mistakes and factors that all combine to create a catastrophe. The importance of aviation personnel possessing both technical knowledge and soft skills is highlighted as keys to operating safely in the high-paced world of aeronautics. Different accident causation models are exposed to help understand the intricacies behind accidents. This chapter also introduces a new name for the famous "5-M" model. Given that one of the "Ms" used to stand for "Man," the new model changes that one factor to "human" and the entire model is now called the "5-Factor" model.
- Chapter 3 is a foray into the fascinating world of human error. The discussion centers on how external factors, such as vibration, and internal factors, such as cognitive biases, can combine to negatively impact human performance. An introduction to Situation Awareness (SA) is provided and tied to the difficulty of designing automation that is intuitive, transparent, and predictable.
- Chapter 4 turns the tables on the previous section by explaining how humans are not only sources of errors, but also can be used as agents of accident prevention. Through the skillful use of leadership and followership on the flight deck, pilots can detect loss of Situation Awareness (SA), work to sustain and build SA, and regain SA once lost. A depiction of the opportunities of working in groups versus working individually is featured as a key concept in Crew Resource Management (CRM) and Threat and Error Management (TEM).
- Chapter 5 discusses government regulations that keep commercial aircraft operations safe. The section debunks the commonly held belief that the airline industry in the United States is deregulated by showing that it is in fact very regulated when it comes to safety and explains the rulemaking and explains the rulemaking processes that create a safety net over which we fly every day.
- Chapter 6 is on accident investigation. Many of the improvements in aviation safety stem directly from the forensic analysis of tragedies. Government investigating agencies are described and several key recommendations that were enacted due to aircraft accidents are showcased.
- Chapter 7 on proactive and predictive safety provides a stark contrast to the

conventional reliance on accident investigation to improve safety. Over the past half century of flight, early adopters of flight data monitoring and voluntary reporting programs have reaped the benefits of staying ahead of emerging hazards. The philosophy of proaction is explained to understand the value of crafting recommendations that are not based on accident forensics.

- Chapter 8 is the first of three sections in the text dedicated to understanding how system designs set up commercial aviation for safety success. Aircraft design requirements are explored to include technologies that assist safety while expanding the operating capability of aircraft in circumstances that are inherently hostile to flight, such as icing and low visibility.
- Chapter 9 spends time discussing the role played by airport design in aviation safety and investigates recent advances being fielded to address runway incursion and excursion risks. Special mention is made of the critical interaction between Airport Rescue Fire Fighting (ARFF) crews and aircraft flight crews during emergency procedures.
- Chapter 10 dives into the medium in which commercial aircraft operate to show that the safety of air traffic is directly tied to the design of airspace. Special attention is given to the transformation of airspace underway due to the digital revolution that is part of the FAA Next Generation (NextGen) initiative and similar international Air Traffic Control initiatives.
- Chapter 11 deals with safety data and undertakes the critical task of explaining how both qualitative and quantitative data are collected, fused, and analyzed to determine operational risk. An associated discussion is presented on safety culture, since the voluntary reporting of safety data is a fundamental offshoot of a healthy workplace environment.
- Chapter 12 organizes previous material under a single approach for consistently dealing with actual, versus perceived, risk via a Safety Management System (SMS). Recent international and FAA guidance is featured to explain the role played by aviation maintenance technicians, flight crew, and support personnel. The four components of SMS are discussed in detail including implementation and future challenges facing aviation certificate holders. The entire chapter has been updated to reflect the new SMS requirements of 14 CFR Part 5.
- Chapter 13 deals with security issues, also known as protection from intentional harm. The adaptive nature of terrorist threats requires methods for continuous improving our precautions to include information gathering and processing as well as counterterrorist actions and airline security measures.

- Chapter 14 presents some of the most important emerging issues in commercial aviation safety by describing both challenges and opportunities. Some of the challenges remain unmet in recent years, such as accurate detection and prevention of the aerodynamic impact of aircraft icing, the difficulty of oceanic tracking, and the need to design automation to deal with human information processing limitations. New emerging safety areas include the looming difficulty of integrating Unmanned Aerial Systems (UAS) and commercial space vehicles into airspace shared by conventional commercial aircraft and newly highlighted threats posed by software errors and cybersecurity issues. The relatively recent advent of online education and aviation doctoral programs are tools that present unique opportunities for exploring the emerging challenges of commercial aviation safety.
- Tables, figures, statistics, key terms, review questions, and references contained in this text have been updated and revised.
- Numerous Web sites have been included to help students and instructors utilize the vast amount of information available on the World Wide Web.
- Each chapter contains a number of features that are designed to facilitate student learning. These features include the following:
  - *Chapter outlines*. Each chapter opens with an outline of the major topics.
  - *Learning objectives*. The objectives of the chapter are included so students know exactly what is to be accomplished after completing the material.
  - *Relevance*. All examples, applications, and theories are current as of this writing.
  - *Incident examples*. Vivid and detailed descriptions of incidents are included whenever appropriate to illustrate concepts by making use of NASA's Aviation Safety Action Reporting database.
  - *Figures and tables*. Figures and tables are drawn from sources such as ICAO, NTSB, Airbus, Boeing, and other current Web sites.
  - *Logical organization and frequent headings*. Itemized bulleted lists are used as frequently as possible to enhance reading.
  - *Key terms*. Each chapter concludes with a list of key terms used in the text.
  - *Review questions*. Review questions at the end of each chapter cover all of the important points. This new edition of the text enhances the question section by providing themes conducive to class discussions.
  - *Suggested Reading and Web References*. A list of Suggested reading and web references is included at the end of each chapter for students who wish to pursue the material in greater depth.

ACKNOWLEDGMENTS

Publication of a milestone such as the Sixth Edition of a textbook that has endured 26 years in such a dynamic area as Commercial Aviation Safety truly humbles the current authors. While acknowledgments are too numerous to mention, we wish to express our sincere thanks and gratitude to Dr. Alexander T. Wells, Professor Emeritus at Embry-Riddle Aeronautical University, a prolific writer who was the original author of the book. As always, we are sincerely appreciative of the many public and private institutions that have provided resource material for this edition. We are particularly indebted to the International Civil Aviation Organization, Federal Aviation Administration, National Transportation Safety Board, Department of Homeland Security, Occupational Safety and Health Administration, Environmental Protection Agency, the Boeing Company, and other industry partners for their numerous publications. A special thanks for the dedicated support from faculty, administration, and support staff of the Florida Institute of Technology, Embry-Riddle Aeronautical University, and The Petroleum Institute. We truly appreciate the dedication of Ms. Amber L. Davis of Daytona Beach for her professional assistance in researching and editing the material contained in this edition.

We are also grateful to the editors at McGraw-Hill Education for their contribution, especially Lauren Poplawski, Lauren Rogers, and Lynn Messina; and Apoorva Goel, at MPS Limited, who worked as the Project Manager on this book.

Finally, we gratefully thank our families for their patience and encouragement in this project, especially our wives Jean, Diane, and Nicola who made this effort possible.

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CHAPTER ONE

INTRODUCTION TO COMMERCIAL AVIATION SAFETY

LEARNING OBJECTIVES

LEARNING OBJECTIVES

After completing this chapter, you should be able to

- Dispute common myths about safety and provide reasoning as to why the myths are not true.
- Discuss safety ethics and why they are important.
- Explain the difference between safety and security and how they relate to commercial aviation.
- Name significant aircraft accidents and detail how they changed regulations in aviation.
- Differentiate between retroactive safety, proactive safety, and predictive safety and identify where modern safety systems are today.
- Describe current safety programs that have been developed to improve commercial safety.

INTRODUCTION

Signs of safety are all around us. Speed limits and the types of lines painted on roads are set according to conditions presented by different stretches of road. Fire extinguishers, sprinklers, and exit signs are ubiquitous in buildings. Sneeze protectors cover salad bards to promote food safety. Cars have antilock brakes and air bags. Maintenance staff put up “wet floor” signs to warn people of slippery floors. Signs of security are also all around us. Passcodes on phones prevent others from accessing private information. Online accounts require passwords to access sensitive areas. Security at airports checks passengers to ensure they are not taking dangerous items onto planes. No matter what the context at hand is, safety is not an accident, and security requires constant vigilance. These topics are an integral part of any discussion, especially in the aviation industry.

For example, minimum training standards are written for flight attendants to promote the prompt evacuation of passengers during cabin fires, ramp agents wear reflective vests to reduce the chance of being run over by vehicles, some maintenance procedures require the use of eye protection to reduce the change or puncture injuries, pilot callouts help ensure that everyone on the flight deck is aware of emerging problems that may impact safety, fluid quantities are restricted in carry-on bags, cockpit doors are reinforced to prevent forced entry, and passengers are screened to prevent weapons from being in aircraft cabins.

In 2015, Chairman Calin Rovinescu of the International Air Transportation Association (IATA) said that safety is the number one priority for commercial aviation, and it will continue to be so. But is safety truly the most important issue in commercial aviation? After all, the word “commercial” implies that profit is important. This book will depict the key elements of providing for safe and secure operations, not as impediments to making a profit in the aviation industry, but as prerequisites!

What exactly is commercial aviation safety? First, let us examine what it involves. There are different sectors of aviation, all of which use aircraft and people for a variety of tasks. The following categories sum up the major uses for such assets:

- *General aviation*—civilian flying that excludes scheduled passenger airlines
- *Corporate aviation*—air transportation specifically for the needs of company employees and executives
- *Military aviation*—use of aircraft for conducting aerial warfare and support operations
- *Commercial aviation*—using aircraft to provide paid transportation or flight services to people and cargo.

This book explores the aspects of safety in relation to commercial aviation. To a lesser but also important extent, issues dealing with security are also exposed. Ultimately, one of the major goals in these realms is enhancing the efficiency of aircraft operations while preventing events that cause injury to people or damage to equipment. The industry centers around rules and regulations aimed to seamlessly and safely transition aircraft, passengers, and workers through every phase of a flight.

Focusing on the commercial sector is not meant to imply that huge strides in safety have not been made. Enormous improvements have turned commercial aviation into an extremely safe and mostly reliable form of transport. Similarly, focusing on commercial aviation is not meant to say that the concepts covered in the book do not apply to other realms of aviation or even to other types of industries. In fact, most topics covered are applicable to all the branches of aviation, and furthermore, a wide range of industries.

For example, health care is very concerned with safety. The Institute of Medicine claims that 700,000 patients suffer from medical errors in the United States every year. Between 44,000 and 98,000 die from these mistakes, and some conservative calculations claim that medical mistakes are the eighth leading cause of deaths. We can put this figure into perspective for aviators, as it

leading cause of deaths. We can put this figure into perspective for aviators, as it is comparable to having a fully loaded Boeing 747 crash every 3 days. Regardless of which industry we could name, safety is, and will continue to be, an integral part of the discourse. Therefore, anyone desiring to pursue a career anywhere in the industry absolutely must understand the concepts of safety presented in this book.

We focus on commercial aviation because it is a type of *ultrasafe high-risk industry (USHRI)*. Along with other industries, such as nuclear power and chemical, commercial aviation accomplishes its mission while having less than one disastrous accident per 10 million events. USHRIs are described as facing very high risks on a constant basis, but somehow not succumbing to them except on rare occasions. Within these domains, the smallest mistake could have huge consequences and jeopardize safety for many. The excellent level of safety these industries see today has evolved, to a great extent, from crisis-laden events. When something disastrous, such as a death, shocks the community, people are moved to create regulations to prevent that event from occurring again.

In USHRIs, accidents are understood to result from a combination of elements, whereas any of these elements on its own would likely not cause an accident or serious incident. Compare these work environments, though, to others that suffer less immediate and grave circumstances. Think of those who work in human resources, education, or clerical settings. Although mistakes in any setting can result in harm, the chances of small mistakes resulting in very grave harm are rare in such settings. Little mistakes do not cause high damage. Although USHRIs have drastically minimized errors compared to other industries, they have also been working on it for a while and are benefiting today from the disasters and efforts of yesterday. Figure 1-1 shows a captain operating the flight guidance panel to maneuver a modern airliner in the proximity of high mountains above South America. Over a century of safety improvements have made the commercial aviation industry ultrasafe, but is it safe enough?

FIGURE 1-1 Flying a modern commercial airliner near the Andes Mountains of South America.

Before going any further into commercial aviation safety, it is important to understand that there is a difference between what is considered an incident and what types of events are actually termed an accident. The term *incident* is somewhat ambiguous because there is not a general agreement of what it entails. The Federal Aviation Administration (FAA), National Transportation Safety Board (NTSB), and International Civil Aviation Organization (ICAO) all have different definitions they use to describe incidents. Simply put, an incident is something that happened during the operation of an aircraft which did or could affect the safety of operation but which did not rise to the severity of an accident. An incident could include a crewmember not being able to perform a normal flight duty because of injury or illness, an inflight fire, or a flight control failure. In contrast, an accident is an occurrence that involves some degree of injury or damage related to the operation of an aircraft. There are different variations of

the definition of an accident, but ICAO's definition is the most widely accepted in the commercial aviation sector. There are four types of accidents identified for the commercial sector according to ICAO:

- *Major accidents*—occur when an aircraft is destroyed, there are multiple fatalities, or there is a fatality coupled with a substantially damaged aircraft
- *Serious accidents*—happen when there is either one fatality without substantial damage to an aircraft or there was at least one serious injury and an aircraft was substantially damaged
- *Injury accidents*—nonfatal accidents with at least one serious injury and without substantial damage to an aircraft
- *Damage accident*—characterized by no one getting killed or seriously injured, but an aircraft receiving substantial damage

WHAT IS RISK?

In the context of safety, risk is the combination of the severity of a dangerous condition or event and the probability or likelihood of that event occurring. For example, is it risky to walk barefoot across a field that has snakes? It is not risky at all if the field has nonvenomous or low-venom snakes, assuming you are not terrified of snakes and have a panic attack. But the same act with highly poisonous snakes in the field, such as cobras, can greatly increase the severity and therefore the risk. That explains the severity of the situation, but what about the likelihood of injury?

If there is one cobra in the field, and you only have to cross the field once, then the likelihood of injury is quite low. If there are a dozen cobras in the field and you have to cross the field once, the likelihood of injury may be deemed moderate. However, if there are a dozen cobras and you have to walk across the field to get to work every single day, then the likelihood of injury may be seen as very high. So the lowest risk is when there are no venomous snakes or low-venom snakes (low severity) and very few of us crossing the field only once (low likelihood), and the riskiest situation is having cobras (high severity) and many of us facing the cobras often (high likelihood). If you can avoid walking across such a field in the first place, you have eliminated the risk. But if you must cross the field, perhaps you can change the severity or the likelihood so that it is in your favor … so that you lower the risk. To mitigate the risk, you can change the severity of the threat by wearing tall boots, and you can change the likelihood of injury by crossing the field less often.

Aviation safety follows similar risk management principles. Let us take a regional airline operating in sub-Saharan Africa with service into an unpaved airfield. The airfield's eastern edge is very close to the shore of a large lake. However, there is a hazard posed by crocodiles that like to sun themselves on the runway. The larger crocodiles often hunt at night and like to sun themselves in the morning and early afternoon. The younger crocodiles are too intimidated by their larger kin and only sun on the runway when the larger crocs have left, which is usually around 5 pm when the larger crocs go back to the water for the night's hunt.

The severity of the hazard is related to the speed at which the aircraft could impact a crocodile and the size of the crocodile. The likelihood of collision could be explained as the times when the aircraft comes close to impacting a crocodile when operating at the airfield. Imagine that you have been hired by the airline, and the vice president of operations calls a meeting to discuss safety. He asks the question, how can we improve safety at the crocodile airfield? Some of the airline employees, when faced with such a question, may answer, "That's easy, we just shouldn't fly there." But safety is not about impeding a task, it is about mitigation of risk or doing it better. After all, the population in the area near the airfield depends on the scheduled air service for medicine, supplies, and personal transportation. What would you suggest to the vice president?

If you understand the concept of severity and likelihood in risk, you may recommend any of the following, or all of the following:

- Reduce the likelihood of an encounter by contracting a local to scare the crocodiles off the runway for your time of landing and takeoff. That may require a brave employee!
- If winds allow, land and takeoff from the western part of the runway to reduce the likelihood of running into crocodiles.
- Operate into the airfield after 17:00 hours but before sunset so that you reduce the *severity* of any collision with crocodiles, since you will probably only hit the small crocs and not the large ones. It is prudent to operate only during daylight hours so that you can see any crocodiles on the runway.

As you can see in the previous example, aviation safety is nuanced and requires significant study in order to be used effectively as a way to enhance operations versus as a way to say "no" to operations. Given the size and complexity of commercial aviation, it is no wonder safety is a major topic. Looking at some statistics helps break down just how large aviation operations are and just how many opportunities there are for safety to decay. IATA reported

that 3.3 billion people flew in 2014 and projected this number would increase to 3.5 billion on more than 50,000 routes in 2015. Every day, it means that over 8 million people are in the sky on more than 100,000 flights. There are more than just people moving through the sky, as pilots transported 50 million tons of cargo. Transporting people and goods resulted in a $2.4 trillion international economic footprint that supported 58 million jobs globally. When taking all those numbers into consideration, it is astonishing that in 2014 there was only one major accident for every 4.4 million flights. How is it possible to operate so safely?

The growth of the aviation industry is not forecasted to slow down, either. The ICAO Regional Aviation Group expects the Latin America and Caribbean airline industry to grow 5–9% yearly into the foreseeable future. Currently, the airline industry in this region creates $158 billion in revenue and 4.9 million jobs, with an anticipated growth to $289 billion and 9.8 million respectively by 2032. Likewise, Airbus predicts current airline traffic is supposed to more than double by 2034 for the Asia-Pacific region. Worldwide in 2014 there were 47 aviation megacities, locations that have more than 10,000 daily flights that are between 6 and 12 hours. In 2034, this number may rise to 91 megacities.

Most importantly, it is essential to understand why we care about commercial aviation safety. First and foremost, human life is involved, often in significant numbers and also often involving not just passengers but bystanders on the ground. Ensuring people do not get hurt is a main priority. Second, when safety deteriorates, it comes with financial implications. These can come in the forms of lawsuits, insurance claims, and stock instability.

Nothing illustrates this point better than the story of the Boeing 787 Dreamliner. The aircraft contained a lithium ion battery unit in the aft electrical bay. The battery was designed to start the auxiliary power unit and provide backup lighting for the aircraft. In January 2013, there were several instances of this battery catching fire. A relatively minor problem, but when paired with a brand new aircraft type that was trying to gain purchase orders, major consequences followed. Within hours of the news about the battery, Boeing lost $2.6 billion of its company value in the stock market as jittery investors started worrying about the future sales of the aircraft. That is “billion” with a “B.” Some companies and governments will incur huge financial impacts just in order to prevent safety from degrading or to prevent the appearance of not taking safety seriously. When Iceland’s Eyjafjallajökull Volcano erupted in April 2010, the industry cancelled around 17,000 flights per day due to unsafe flying conditions. In turn, this resulted in $200 million losses a day. However, one aircraft loss would have been far more.

would have been far more.

SAFETY PHILOSOPHY

Philosophy is the study of reality, existence, and the nature of knowledge. Although it does not take a philosopher with deep thoughts to define safety philosophy, there are quite a few concepts about the nature of safety that are not obvious. Unfortunately, there are industry professionals who believe, quite incorrectly, that safety is merely common sense. At its core, safety is about making life better by addressing unacceptable risks. Something seemingly so simple turns out to have many nuances. Let us debunk some common myths about safety:

- *Accidents happen to stupid people*. People may think “I’m not stupid, so I have nothing to worry about.” Wrong! Accidents can happen to anyone if the right conditions are there because often external factors outside of one’s control combine to work against an individual. For example, a ramp agent may say that the engine area is clear and prompt the pilot to start an engine for departure, only to realize when it is too late that a baggage cart was too close to the engine intake and was sucked into the engine, causing millions of dollars’ worth of damage.
- *If it isn’t broken, don’t fix it*. Very often, we may think something is not broken, but there are often numerous unknown factors at work that may not be in optimal condition. For example, when asked about the condition of their aircraft prior to a flight, some pilots think they are funny by saying, “Well, I figure if it flew in, it will fly out!” Such a statement shows a pilot’s ignorance to the many unknown factors that can prove the statement wrong, such as fluid leaks, ramp collisions, and ground icing; any of which could result in a fatal crash of the aircraft after takeoff.
- *If it hasn’t been a problem before, then it isn’t a problem*. This mindset is a slippery slope. Just because a certain factor has not been an issue before does not mean we should ignore it. There is always a first for everything. For example, modern engines are designed to minimize failures that affect the rest of the aircraft, other than the loss of power. Furthermore, one system failing should not cause another system to fail. But in November 2002 the pilots of Qantas Flight 32, flying an Airbus 380, experienced an uncontained engine failure that also severed electrical wires, hydraulic lines, and a fuel tank.
- *You have been sufficiently trained*. If employees are sufficiently trained to do

everything, we would be training our whole life and never have time to move passengers around the world. Determining what situations to include in the training curriculum for airline professionals is extremely challenging since we cannot be sure of what situations may be faced. For example, in September 2010 the captain of UPS Flight 6, flying a Boeing 747-400, had an oxygen mask failure while attempting to manage an inflight fire. Both pilots perished in the ensuing crash. It is inevitable that we will face situations we are not expecting.

- *Safety is our top priority*. Safety should always be on our mind, and we should strive to operate safely at all times, but let us not kid around, the top priority of any commercial venture is profit. The stockholders and managers of an airline do not place safety as the top priority because the best way to guarantee that an airline is safe is not to fly. Well that would not make much business sense, would it? The question is not how to achieve safety, the question is how to operate and achieve profit objectives in a safe manner. Having said that, we must remember the story of the Boeing stock price plunge due to a safety event and acknowledge that there is a direct link between safety and profit.
- *Accidents are impossible to predict*. Although Chapter 14 will address research efforts underway to create short-term prediction of accidents, it is currently outside of our capability to predict specific accidents with any degree of accuracy. However, that is not to say that we cannot recognize developing accident chains by noticing the presence of undesirable factors. It is not uncommon after an accident for certain employees to comment, “Yes, it was obviously an accident waiting to happen.” In the minds of such employees the factors that created the accident were obvious to them, yet nothing was done to address the factors, and an accident ensued. Often we see a threat but rationalize that it does not pertain to us, leaving the threat lingering. Some threats are obvious, while some threats are not. The same threat may create an accident in one flight, just an incident in another, and have no adverse impact to another flight. So types of accidents and their causal factors are not impossible to predict, but specific accidents to include when and where they will occur are outside of current predictive capabilities.
- *Weather is a leading cause of accidents*. This myth creates much debate in the aviation industry. Adverse weather is often a factor in accidents. However, those who are purists about accident causation stress that weather cannot be deemed a causal factor in accidents. That is because in accident theory, as shall be covered in the next chapter, accident investigations should produce

prompt, remedial recommendations written to prevent future recurrence. For example, if wind shear was a factor in an aircraft accident, we cannot write a recommendation against the wind shear because weather cannot be prevented. So instead of determining weather as a cause it is often the human role in reporting or avoiding weather that is deemed causal. For example, if an aircraft crashes on approach due to wind shear, and the crew was completely unaware of wind-shear conditions due to a malfunctioning wind-shear warning device at the airport, the cause of the accident would not be the wind shear itself but may be faulty inspection protocols for the reporting equipment.

- *There is often a single cause behind an accident*. This is a blatantly false myth. In fact, just the opposite is true. Accidents are complex events stemming from multiple causes. It is quite challenging to think of any accident that only had one cause. Anyone who says so probably has not looked into the factors that contributed to what they believe is the single cause. Historically, accidents were often conveniently written off by deeming the cause to be “pilot error” or “maintenance error” and taking minimal further action. The public was relieved to know that a single “bad apple” had created the problem, and the aviation world could return to business as usual. Clearly more is going on to cause accidents than just bad pilots. In fact, a series of negative factors combine to create accidents. Often the flight crew is only the last link in the chain of factors prior to an accident. Over the past few decades, investigators have shown that accidents usually have more than one cause, and each cause carries the same amount of importance. In fact, in 1994, the NTSB began listing probable causes in the accident report, thus the genesis of the *multicausality* concept. Digging deeper into the causes allows investigators to determine the root cause of why things happened the way they did. One byproduct of this investigative exposé has been the decreased use of the myth of pilot error and realizing that there are flaws in the whole system.
- *Accidents are “Acts of God.”* Above we mentioned that many people tend to think that accidents are impossible to foresee. For so long, we thought accidents just happen. They were mysterious occurrences that no one could control. In many parts of the world, to this day, after accidents people can be heard claiming that the event was an “act of God.” Doing so brings psychological comfort because it removes ties to the truth that most accidents are preventable, if the right people are provided the right tools at the right time. Those tools may come in the form of information, technology, training, or procedures. As humans, we need to embrace the concept that we are

masters of our own safety destiny by relying on scientific tools such as forensics and logic to understand accidents, and then apply the lessons learned from prevention. Yet corners of the planet still embrace the purported inevitability of accidents, and such archaic thoughts do not just stem from the uneducated. For example, managers of Nepal's state-run airline in 2007 sacrificed two goats to Akash Bhairab, the Hindu sky God, in order to resolve a technical problem with a Boeing 757. After the ritual a senior airline official reported that "the snag in the plane has now been fixed and the aircraft has resumed its flights," without explaining what the actual problem had been.

In stark contrast to simply shrugging shoulders and leaving safety up to nonhuman forces, modern aviation professionals should be trained to actively search for negative factors that are coming together that could potentially create an accident. There are several challenges, however. We are constantly surrounded by such signals. Recognizing which signals should be acted upon can be challenging. Nevertheless, there are several conditions that are often notorious precursors to accidents, as listed below. There are many other such preconditions, but for now we will only address these five:

- *Distraction*. Aviation professionals can let other things affect their concentration, such as checking personal text messages during a preflight check.
- *Rushing*. Someone may take a shortcut. When we do this, we are not giving our personal best and we risk missing key information and skipping items that may not seem important now but that could prove critical in a few moments.
- *Operating outside one's training*. Accidents can occur when we find ourselves doing something outside what we are trained to do. We often know that it is something we have not been trained to do and make a conscious decision to do it anyway.
- *Desensitization*. It is easy to tune out warning signs when it is something that frequently occurs and which have not resulted in problems in the past. The problem is that the context may be different today, and therefore today may be the day that the warning applies.
- *Ignoring your instinct*. That expression may not sound very scientific, but it essentially means that something does not feel right. Professionals should not feel uncomfortable when they are doing a task. If something does not feel right, it may be our protective instinct kicking in and recognizing that an unresolved discrepancy or problem is lurking in the background, ready to ruin

your whole day.

Safety Ethics

A discussion of safety philosophy would not be complete without delving into ethics. As aviation professionals, detecting precursors is an ethical obligation to making decisions. When an accident occurs, it is not uncommon to hear someone say, “That was an accident waiting to happen!” However, that very expression means that conditions had previously been recognized that were favorable for an accident. If we knew the possibility existed, why did we not do anything? One key philosophy shared through this book is the need for aviation professionals to develop a mindset that each person can make a difference in safety. When we see conditions developing that can result in an accident, it is important to address the situation immediately or notify the proper personnel who can take action. Everyone must watch for dangerous conditions and have the proper safety ownership to report problems to management, and every manager should be trained on what to do when such a report is received. It takes a team effort by all for safety to be present in commercial aviation.

Accidents do not happen out of the blue, instead there are precursors that are usually detectable by one means or another. The National Academy of Engineering defines precursors as *an event or group of events that must occur for an accident to occur in a given scenario*. As such precursors linger unaddressed they form part of what some safety professionals call a *disaster incubation period*. Although there is no such thing as absolute safety, certain risks can be managed to the extent that they are no longer a significant problem. Where that line lies, that fuzzy line between acceptable and unacceptable risk, is often hotly debated and varies from risk to risk and with operational context. There are limits as to how low we can reduce certain risks without severely impacting operations, and there is a point in which introducing more safety measures significantly outweighs the safety benefit. Safety managers are tasked with the challenging task of reducing risks to as low as reasonably practicable, which is a concept known by the acronym *ALARP*. Keep ALARP in mind as you read the book and especially when safety management is addressed in Chapter 12.

Another element of safety ethics is the need to be respectful when we discuss people having been hurt, such as when we talk about commercial aviation accidents. Ethics is important because human beings are not objects, and everyone has intrinsic worth. A part of this is acknowledging that we are all beings with human feelings. Therefore, it is important to use the appropriate tone

when talking about accidents, as we realize that some accidents involve human suffering and death.

There are a few antiquated mindsets about the victims in an accident that deserve discussion. One is thinking it is the victim's fault that something happened. This is sometimes known as "blaming the victim syndrome." After all, no one plans to have an accident. With accidents being multicausal, it is unfair to hold the persons involved entirely responsible for what went wrong. Psychologists explain that there is a natural human tendency to "blame the victim" because whenever we differentiate ourselves from those who suffer we create comfort in the knowledge that we do not have to worry about the situation happening to us. The explanation is called, "distancing through differencing." For example, when we hear of an automobile fatality we often search for factors that make us feel safe. Perhaps the accident happened at night and the casualty was not wearing a seat belt. Knowing such facts we may be tempted to say, "Well I never drive at night and always wear a seatbelt, so such an event would never happen to me."

As aviation professionals we must bear in mind that blaming the victim usually accomplishes nothing more than bringing us comfort. It certainly does not add to the safety value chain. As Mark Twain purportedly once said, "It is curious—curious that physical courage should be so common in the world, and moral courage so rare." Making ethical decisions and taking ethical action can be complicated and difficult. It involves multiple layers: figuring out the facts, interpreting the facts, and overlaying a set of values on the situation. The right thing to do may require an action that frightens us, such as standing up to a superior or admitting we were wrong. In aviation, when people's lives are at stake, we must always have the moral courage to act in the name of safety.

There is a good story of an aviation professional demonstrating ethics for the sake of safety. In 2007 Comair, a subsidiary of Delta which has now been shut down, fired pilot Shane Sitts for refusing to fly an aircraft that had a broken power device that assists in opening and closing the main cabin door. The malfunction required that the door be opened and closed by hand. Sitts said it was the fifth time in 5 years that he had seen the problem, which raised questions about the integrity of the plane in flight. Sitts also noted that ground crews were constantly endangered by the broken door since the doors would fall open heavily onto the ramp area if the wrong technique was used to open the door in the broken condition. After being fired, Sitts sued Comair and won the case because he was within his rights to refuse to fly due to safety concerns. Although Sitts may have been deemed a whistleblower by coworkers, he stood up for something that gave him an uneasy feeling. Through doing so, he embodied the

epitome of moral courage and ethics.

However, before every reader goes out and tries to be morally courageous to improve safety, we must remember that safety management is a science-based endeavor that requires very careful orchestration. One key aspect that safety managers must consider before attempting to solve problems is the so-called “law of unintended consequences.” Every initiative must be assessed for potential negative outcomes before operations are changed. Sometimes, we act on goodwill to make something better, but in reality, it worsens a situation. Here are some examples from the world of safety:

- Air bags initially caused serious injury or death to small people when activated for collisions that otherwise would not have caused injury.
- Making LED bulbs the new standard for aircraft warning panels removed the ability to collect forensic evidence about which lights were illuminated during impact for accident investigations.
- A Johns Hopkins University 2013 study of 2,323 medical interns to assess safety after reducing duty hours from 30 hours to 16 hours actually revealed the presence of *more* cumulative mistakes, not less, due to increased handoff errors and decreased variety of training.
- In an effort to reduce landings from unstable approaches, some airlines mandated that pilots perform go-arounds from all unstable approaches but did not provide increased training on how to perform the go-around procedure, which can sometimes consist of numerous complex steps in rapid succession while close to the ground and close to stall speed. In essence such a situation removes one risk but possibly replaces it with an even greater risk.
- In some aircraft operations altimeter and navigational accuracy was greatly enhanced in order to operate with less separation from other aircraft, but aircraft collision warning systems were not increased. In at least one case, such a situation led to two aircraft fatally colliding with each other at 35,000 feet when flying in opposite directions at precisely the same altitude and airway. One aircraft was flying at an altitude that was inappropriate for the direction of flight.

SAFETY VS. SECURITY

It is impossible to fly in the airline system today without being aware of security. Although many travelers complain about having to take off shoes and discarding liquids when going through security, most understand that the requirements are

the result of measures taken to prevent the recurrences of previous terrorist and criminal acts involving commercial aviation. Since the September 11 attacks of 2001, in which commercial flights were hijacked and crashed into New York City's Twin Towers, the Pentagon in Washington, D.C., and a field in Pennsylvania, aviation security has received much attention.

Many travelers tend to use "safety" and "security" interchangeably when they speak. In some languages, the same word is actually used to mean both safety and security, but most English-speaking aviation safety professionals make a clear distinction between both terms. Safety entails the prevention of unintended negative outcomes and, therefore, safety specialists attempt to detect those conditions that could lead to personal harm or material damage. However, security entails the prevention of *intentional* negative outcomes, often associated with terrorism and criminal acts. Security specialists focus on intelligence to detect efforts that are underway to harm people and property and also on physical security measures to impede plans once they are underway.

The primary difference between safety and security is intent. The same harm or damage can be produced due to safety or security issues, but it is the human intentional act of producing harm or damage that makes the difference. Let us look at a hypothetical situation to understand this distinction. Imagine a ramp worker who drives a fuel truck into the wing of an airplane. Was it a safety event or a security event? Well, that determination depends on the intent of the driver. We must ask questions. What were the circumstances behind this event? Did the driver do this because she was angry about having to work on Christmas day, or did she drive into the wing unknowingly because she was distracted when answering a text message from her boyfriend? It is necessary to determine whether malice or distraction caused the crash because it dictates the type of investigation that will be conducted and what specific measures can be recommended to prevent the situation from happening again in the future.

If the fuel truck driver acted intentionally, then it was criminal activity, and law enforcement authorities need to assess blame and levy the proper charges. However, if distraction was the cause, then the crash was an accident, and safety authorities will investigate the causes and draft appropriate recommendations. We care about this difference because distinct skills sets are required to investigate the event depending on whether it was intentional or not. One type will require trained investigators in human error while the other needs a law enforcement background to explore the criminal intent.

Looking at changes Boeing has implemented in aircraft design helps illustrate this difference. Since human error is involved in many if not all accidents, in some form or fashion, Boeing focuses on studying human factors, such as flight

some form of fashion, Boeing focuses on studying human factors, such as flight deck design, cognitive psychology, ergonomics, and human performance. By understanding these disciplines, engineers can improve the interaction between human and machines, thus improving the safety of flight. Aside from safety, on the security side, Boeing is designing enhanced security flight deck doors for the 747, 767, and 777 planes. These new doors will have a better ability to withstand bullets, explosives, and blunt force. Additionally, there will be an electronic lock that will give pilots the ability to allow or deny access to flight deck. As one can see, the differences between designing for safety and designing for security have very different goals and require different solutions.

Lastly, it should be pointed out again that the confusion between the terms safety and security can be accentuated when dealing with other languages where the terms are synonymous. For example, in Spanish the word *seguridad* refers to both safety and security, therefore out of convention when *seguridad* is used alone it refers to security but when it is modified with an operational suffix, as in *seguridad operacional*, it means safety.

TENERIFE ACCIDENT

Sometimes security and safety actually affect each other. The worst accident in aviation history provides a perfect example of how a security situation led to a safety event. The example also helps understand the distinction between security and safety. In 1977, a bomb exploded at Gran Canaria Airport, which is on one of the Spanish Canary Islands in the Atlantic Ocean off the coast of North Africa. Fearing the possibility of a second explosive device, planes inbound to the airport were diverted to Los Rodeos Airport on Tenerife, which is another of the Canary Islands. Due to a high volume of traffic at Los Rodeos, air traffic controllers were parking airplanes on the taxiway, thus blocking it. Crews operating into Los Rodeos as a diversionary field were in unfamiliar territory and having to contend with irregular operations on the airfield due to the unusually high volume of traffic.

While waiting to reopen Gran Canaria, a dense fog developed, reducing visibility. When Gran Canaria reopened, two Boeing 747s, one from Pan Am and one from KLM, were parked on the taxiway waiting to depart and started moving as part of the departure sequence. The fog prevented both of the aircraft from seeing each other and also air traffic control from seeing either of the aircraft, so all were relying on voice communication to determine position along the airfield. As the result of several very unfortunate misunderstandings, the KLM flight tried to takeoff while the Pan Am aircraft was still using the runway

to taxi. The two aircraft collided, killing 583 people. Figure 1-2 shows the tragic results of the accident. This story exemplifies how an attempt to address a security concern at one airport actually caused a safety disaster at another.

FIGURE 1-2 Recovery personnel and accident investigators comb through the wreckage of the two Tenerife B-747s. (*Source: Ministerio de Transportes y Comunicaciones, Spanish Government*)

AVIATION SAFETY HISTORY

At the very start of the 20th century, the first fatal accident occurred in 1908 and involved one of the aircraft of the Wright Brothers. Because the aircraft was on a military demonstration flight and killed the military observer who was aboard to assess the flying, the U.S. Army convened an investigation. The Investigation Board concluded that a propeller contacted a wire from the rudder, causing the wire eventually to come off its socket. This caused the rudder to fold sideway, and consequently, the pilot lost control of the plane. Figure 1-3 shows the scene

at the accident site moments after the event.

FIGURE 1-3 The first responders who ran to assist the downed Wright aircraft in 1908. (*Source: U.S. Army*)

Accidents in the military and in civilian aviation continued to happen. In 1921 the U.S. Army was the first to keep statistics on aviation accidents. They recorded that 361 major accidents occurred in 77,000 hours of flight during 1 year alone. That is 467 accidents per 100,000 hours! To put this very high rate of accidents into perspective for operations today, that would equate to losing several thousand airliners per day across the world. Pretty soon we would be out of aircraft to fly! Unfortunately, the U.S. Army did not have a Chief Aviator who understood safety philosophy, as evidenced by the order that he issued to his aviation commanders: “There will be no more accidents!” One shrewd commander sent back a response that said, “Then there will be no more flying,” since he understood that the only way to reduce risk to zero was to halt operations altogether.

Two key events helped shed light on the importance of safety in aviation. During the early part of the 20th century, civilian aviation in the United Sates

During the early part of the 20th century, civilian aviation in the United Sates was not regulated. Many professionals thought that aviation could not reach its full potential in the commercial sector without more stringent safety standards. President Calvin Coolidge appointed a board to explore this issue. The board's report agreed that there needed to be more federal safety regulation. As a result, the Air Commerce Act became a law in 1926 and established the requirements for investigating accidents in response to the aircraft surge during World War I.

The second key event occurred 9 years later in 1937. A German passenger airship known as the Hindenberg was attempting to dock at the Lakehurst Naval Air Station in Manchester Township, New Jersey after a flight from Germany. It caught fire and was destroyed claiming 35 lives with it, and the entire sequence was transmitted over radio much to the horror of a large listening audience. This accident was so dramatic that it ended the airship industry, which was a very large commercial aviation base. Imagine the impact that one single accident had on the public consciousness. It was such a profound event that it ended an entire industry! Figure 1-4 shows the shocking scene of the Hindenburg accident as it was unfolding.

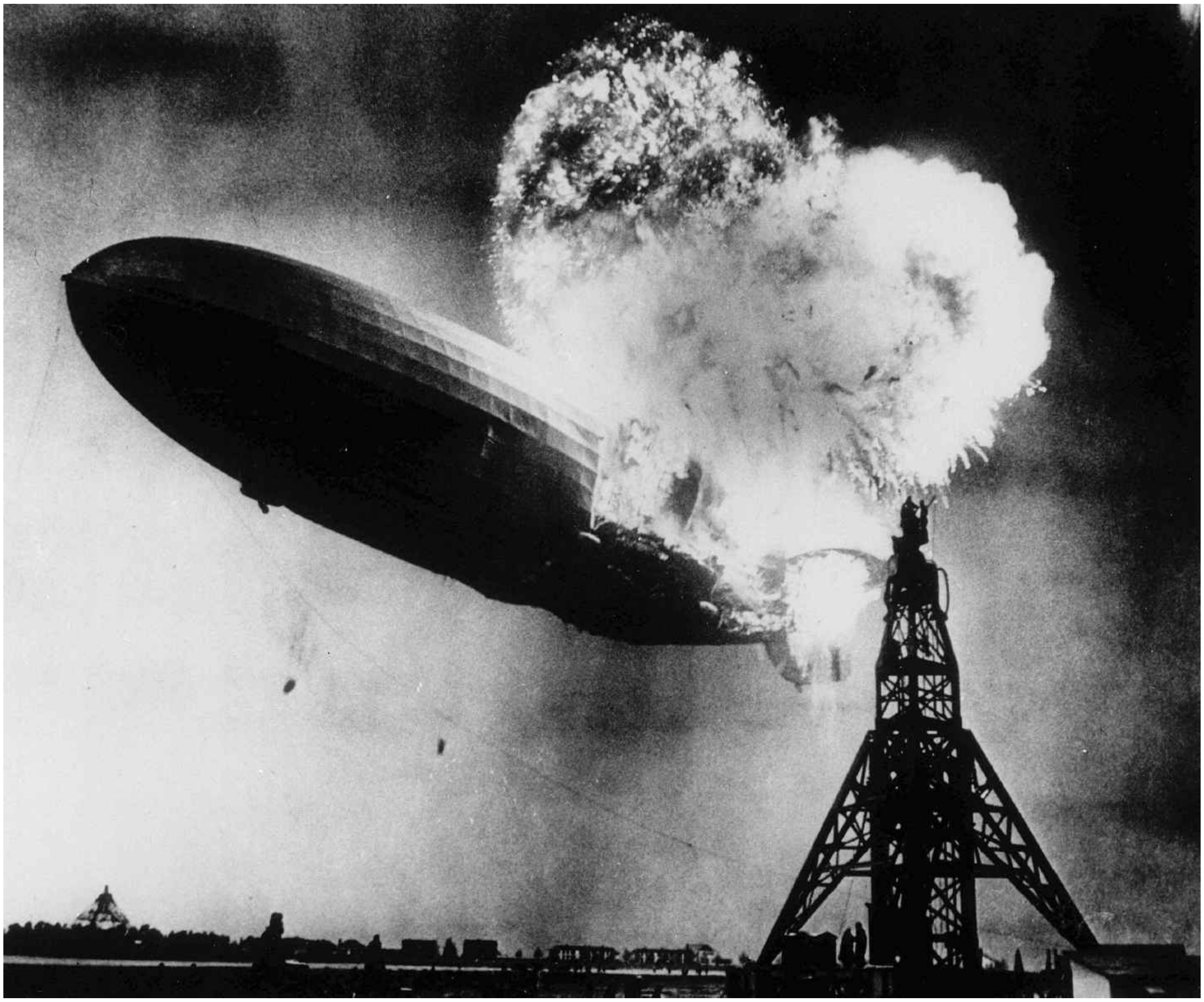

FIGURE 1-4 Photo of the Hindenburg disaster and fire (1937). (*Source: U.S. Navy*)

SIGNIFICANT AVIATION ACCIDENTS

In the airplane segment of commercial aviation there is also a history of significant accidents, plus a history of malicious acts such as terrorist attacks that do not count as accidents. Some accidents and attacks have had such profound significance that they have prompted action. Those actions have shaped the current commercial aviation industry. The list of accidents and attacks that follow is impressive, but unfortunately is by no means exhaustive. The list contains only the most significant events that have helped create a safer world for air travel and transport. Some of the events are referred to in conversations by industry professionals to this day and also during efforts to craft modern legislation in aviation, so the reader is urged to become familiar with the contents of the compilation. Each event has a very long investigation report

associated with it and the details contained in the reports are always of great interest. This list only provides the bare essentials.

- *June 30, 1956*. A United Airlines Douglas DC-7 struck a Trans World Airlines Lockheed Constellation in a midair collision over the Grand Canyon. There were 128 fatalities, and the first airline crash to result in more than 100 deaths. The crash led to drastic changes in how flights are controlled in the United States.
- *December 16, 1966*. A United Airlines Douglas DC-8 heading toward Idlewild Airport in New York City collided with a Trans World Airlines Constellation over Staten Island. There were 128 fatalities, including 6 on the ground. The result of this accident was the introduction of a speed limit of 250 indicated knots when flying below 10,000 feet that is still in effect today.
- *December 1, 1974*. Trans World Airlines Flight 514, a Boeing 727, was flying to Washington National Airport but had to divert to Washington Dulles Airport due to strong crosswinds. The plane was cleared for approach but resulted in a controlled flight into terrain. There were 92 fatalities. As a result, the FAA mandated ground proximity warning systems, and the Aviation Safety Reporting System (ASRS) was also created in 1976.
- *March 27, 1977*. At the Los Rodeos Airport in Tenerife, one of the Spanish Canary Islands, KLM Flight 4805 and Pan Am Flight 1736, both Boeing 747s, were taxiing out for takeoff after diverting to the airport due to a security threat at their intended airport of use on the island of Gran Canaria. Heavy fog was in the area, and KLM Flight 4805 did not see and collided with Pan Am Flight 1736 during the takeoff roll. There were 583 fatalities. To this day the event remains the worst aviation accident the world has experienced. It should be noted that security events are not considered accidents, thus tragedies such as the September 2001 terrorist attacks do not count as an accident. As a result of the Tenerife accident an increased emphasis was put on using standardized phraseology between air traffic controllers and pilot, although some of the factors that helped produced the accident have still not been successfully addressed by the industry.
- *August 2, 1985*. Delta Airlines Flight 191, an L-1011 TriStar, slammed into the ground as it encountered a wind shear on final approach into the Dallas–Fort Worth Airport on August 2. There were 135 fatalities. This accident prompted major changes in FAA training and improvements in Doppler radar weather technology.

- *December 12, 1985*. A military-chartered Douglas DC-8, Arrow Air Flight 1285, crashed on takeoff from Gander, Canada, due to icing. There were 256 fatalities. The flight was transporting members of the U.S. Army's 101st Airborne Division from Egypt back to Kentucky. The accident drew attention to the hazards of ground icing and to the reliance on commercial aviation charters for travel by the U.S. military.
- *August 16, 1987*. Northwest Airlines Flight 255, a McDonnell Douglas MD-82, crashed after liftoff from Detroit Metropolitan Wayne County International Airport due to the flight crew's failure to use the checklist to ensure the flaps and slats were extended for takeoff. There were 156 fatalities, including 2 on the ground. Aircraft manufacturers and airline flight operations managers learned the importance of checklist design and flight deck procedures that foster checklist item completion.
- *April 28, 1988*. Aloha Airlines Flight 243, a Boeing 737, suffered an explosive decompression caused by metal fatigue and corrosion, but was able to land safely in Maui with only one fatality, a flight attendant who was ejected from the aircraft as a large opening was torn in the fuselage and who was never found. As a result of the accident the U.S. Congress passed the Aviation Safety Research Act of 1988 which provided for enhanced research in the critical areas of aircraft maintenance and structural technology. Also in 1991 the Aging Aircraft Safety Act was passed, which called for the inspection and repair of certain components even if they show no visible signs of damage.
- *December 21, 1988*. Pan Am Flight 103, a Boeing 747, suddenly exploded in the sky over Lockerbie, Scotland. All 259 persons on board were killed, plus an estimated 11 on the ground. When British investigators announced a week later that the aircraft was brought down by a bomb, the tragedy became the most deadly act of sabotage ever perpetrated against a U.S. airliner.
- *February 1, 1991*. U.S. Air Flight 1493, a Boeing 737, collided with a Skywest Metroliner on the runway while landing at Los Angeles International Airport (LAX). Both planes were destroyed in the accident, which killed 34 people. The cause of the accident was an error made by an air traffic controller at this extremely busy airport. This type of accident is known as a "runway incursion," a type of accident that was on the list of the NTSB's most wanted safety improvements for many years.
- *March 3, 1991*. All 25 people aboard United Airlines Flight 585, a Boeing 737, were killed when the plane crashed after the crew lost control of the

aircraft in flight due to a rudder problem during final approach to Colorado Springs. The aircraft was approximately 1,000 feet above the ground when the upset occurred. The Boeing 737 had an enviable safety record until that time, and the cause of this accident was undetermined by the NTSB for a number of years. Similar Boeing 737 rudder problems near Pittsburgh and Richmond later on provided answers to solve the perplexing mystery of the Colorado Springs accident. As a result of the 54-month investigation, improvements have been made to the amount of data collected by crash-survivable flight data recorders so that investigators can arrive at the factors involved in similar accidents with greater efficiency.

- *July 2, 1994*. U.S. Air Flight 1016, a Douglas DC-9 approaching Charlotte/Douglas International Airport, with thunderstorm activity in the area, crashed when the crew encountered a wind shear and attempted to abort the landing. There were 37 fatalities and 20 people on board survived the accident. This event brought to an end a 27-month period in which the major U.S. scheduled airlines did not suffer a passenger fatality. The accident helped convince the FAA to pass the Sterile Cockpit Rule in 1981. The rule promotes having only safety-related discussions between the pilots of airliners at certain points of a flight.
- *September 8, 1994*. U.S. Air Boeing Flight 427, a Boeing 737, crashed while on approach to the Greater Pittsburgh International Airport. All 132 people on board were killed and the plane was destroyed by impact, making it one of the worst aviation accidents in U.S. history. This accident was extremely similar to the United Flight 585 rudder control problem which occurred in Colorado Springs. Again, NTSB investigators were baffled at the cause of the uncontrolled rudder problem until another Boeing 737 survived a similar situation near Richmond in 1996. A thermal shock test finally confirmed that the 737 rudder could be subject to a hardover rudder reversal under certain conditions, and it was ultimately reengineered to prevent similar recurrences.
- *October 31, 1994*. A Simmons Airlines ATR-72, operating as American Eagle Flight 4184, crashed south of Roselawn, Indiana. The flight was en route from Indianapolis to Chicago's O'Hare Airport and had been placed in a holding pattern for about 32 minutes because of traffic delays. The weather conditions during the period of holding were characterized by icing, a temperature near freezing, and visible moisture. All 64 passengers and 4 crewmembers were killed in the accident. The accident called attention to the limitations of autopilots and ice detection in aircraft.
- *May 11, 1996*. ValuJet Flight 592, a Douglas DC-9, crashed into the

Everglades shortly after takeoff from Miami International Airport, en route to Atlanta. All 105 passengers and 5 crewmembers aboard were killed, and an extremely difficult recovery operation was required due to the accident site being in swampy land. This accident was caused by the improper packaging and storage of hazardous materials (oxygen canisters) which resulted in a serious aircraft fire, and the ultimate bankruptcy of the airline. Partially as a result of the accident, airliners are now required to have fire detection and suppression systems in the cargo holds.

- *July 17, 1996*. TWA Flight 800, a Boeing 747 on a regularly scheduled flight to Paris, France, crashed into the Atlantic Ocean off the coast of Long Island shortly after takeoff from John F. Kennedy International Airport. All 230 people on board the aircraft were killed. The cause of the accident was an explosion from a short circuit in a fuel tank onboard the aircraft, related to unusual heat experienced during an extended ground delay. When combined with the previously mentioned crash of ValuJet 595, these two disastrous crashes in 1996 resulted in the highest number of fatalities for a single year during the past two decades. The 1996 fatal accident rate per 100,000 departures for scheduled service increased from 0.025 to 0.038, and the rate per 100,000 flight hours rose from 0.016 to 0.023. As a result of TWA Flight 800 crash the industry turned its attention to wiring safety, and the NTSB and FBI increased their collaboration process during the early stages of such events, when it is initially unclear whether the crash is due to a safety or security situation.
- *January 31, 2000*. Alaska Airlines Flight 261, a McDonnell Douglas MD-83, en route from Puerto Vallarta, Mexico to San Francisco, California, reported flight control problems with its horizontal stabilizer and a loss of stability before it crashed into the Pacific Ocean near Point Mugu, California. There were 88 fatalities. As a result of the accident scrutiny was placed on maintenance procedures.
- *July 25, 2000*. Air France Flight 4590, a Concorde supersonic aircraft, crashed on takeoff from Charles de Gaulle International Airport near Paris after striking a titanium metal strip on the runway that had fallen off of a Continental DC-10. The metal strip punctured a tire of the Concorde, and debris ruptured a fuel tank causing a serious fire from which the Concorde could not recover. This type of event is known as Foreign Object Debris (FOD) damage when it strikes another aircraft. There were 109 fatalities. This accident marked the beginning of the end of Concorde. The aircraft was retired 3 years later due to safety concerns and lack of passengers in the wake

of the 9/11 terrorist attacks in New York and Washington. Similar to the Hindenburg accident in 1937, this accident helped eliminate an entire mode of air transport. After the Hindenburg accident the use of airships ceased, and after the Concorde accident the use of supersonic air travel stopped.

- *October 31, 2000*. Singapore Airlines Flight 006, a Boeing 747, crashed on takeoff in Taipei, Taiwan. There were 83 fatalities. The crew of this aircraft lost situational awareness in a rain storm and attempted to takeoff on a closed parallel runway, hitting several large pieces of construction equipment. The accident emphasized the need for pilots and air traffic controllers to confirm that a departing aircraft is lined up on the correct runway prior to takeoff. Unfortunately, this runway lesson would have to be repeated again at Lexington, Kentucky in 2006.
- *November 12, 2001*. American Airlines Flight 587, an Airbus 300-600, experienced a loss of control upon initial climb after takeoff and crashed into a residential area in Queens, NY killing 265. The accident was caused by excessive overuse of the rudder to counter a wake turbulence problem, resulting in a separation of the vertical stabilizer from the aircraft. The accident prompted significant reconsideration of how certain aerodynamic principles are taught to pilots.
- *May 7, 2002*. China Northern Airlines Flight 6136, a McDonnell Douglas MD-82 from Beijing to Dalian, China, crashed after a troubled passenger set the cabin on fire with gasoline to obtain the proceeds from seven insurance policies. There were 112 fatalities.
- *May 25, 2002*. China Airlines Flight 611, a Boeing 747 from Taiwan to Hong Kong, broke up in flight and crashed due to a previous inadequate structural repair to the hull. There were 225 fatalities.
- *January 3, 2004*. Flash Airlines Flight 604, a Boeing 737 from Egypt to France, crashed in the Red Sea with 148 fatalities. The cause of the accident was distraction of the pilot and spatial disorientation.
- *August 14, 2005*. Helios Airways Flight 522, a Boeing 737 traveling from Cyprus to Greece, lost pressurization and crashed with 121 fatalities. The apparent cause of the accident was an improper setting of the cabin pressurization switch which incapacitated the crew and passengers due to hypoxia brought about by depressurization of the aircraft. The plane crashed near Athens after fuel starvation of the engines.
- *September 5, 2005*. Mandala Flight 091, a Boeing 737, crashed on takeoff in Indonesia. There were 117 fatalities. The cause of the accident was failure to

use the checklist, resulting in improper setting of the flaps and slats which were not placed in the takeoff configuration. This accident was sadly reminiscent of the 1987 MD-82 Detroit accident covered previously in this list.

- *May 3, 2006*. Armavia Flight 967, an Airbus 320, crashed into the Black Sea at night on a missed approach in poor weather near Adler/Sochi Airport in Russia. There were 113 fatalities. The cause of this accident was controlled flight into terrain (water) while climbing out with weather conditions below established minima. The official investigative report cited the psycho-emotional stress level of the captain, poor cockpit resource management, and air traffic control problems.
- *July 9, 2006*. In another domestic accident, S7 Airlines Flight 778, an Airbus 310 from Moscow, crashed in Siberia with 125 fatalities. The aircraft failed to decelerate on landing due to inadvertent movement of one throttle to the forward thrust position which caused the plane to overrun the runway and crash into a concrete barricade.
- *August 27, 2006*. Comair Flight 191, a CRJ-100, crashed on takeoff from Lexington, Kentucky. The aircraft took off on the wrong (short) runway due to a loss of situation awareness, and the crew's nonpertinent conversations were in violation of the FAA "Sterile Cockpit Rule."
- *September 29, 2006*. GTA Flight 1907, a new Boeing 737-800, suffered a midair collision at Flight Level 370 with an Embraer Legacy business jet on a domestic flight over the Brazilian Amazon jungle. There were 154 fatalities as the Boeing 737 plunged to the ground, while the Legacy continued flying and was able to safely land. Although the Brazilian authorities initially charged the pilots of the Legacy with negligence, the NTSB report cited a combination of ATC errors that placed both aircraft on the same airway at the same altitude.
- *July 17, 2007*. Tam Airlines Flight 3054, an Airbus 320 on another domestic Brazilian flight, overran the runway and crashed on landing at Congonhas Airport in Sao Paulo. There were 187 fatalities. The investigation indicated that the aircraft thrust reverser was deactivated, causing the plane to run off this short runway.
- *August 20, 2008*. Spanair Flight JK 5022, a MD-82, crashed on takeoff in Madrid, Spain. There were 154 fatalities. The investigation indicated that after an interruption, the aircraft tried to take off in the wrong configuration with the flaps and slats retracted.

- *January 15, 2009*. The “Miracle on the Hudson.” U.S. Airways Flight 1549, an Airbus 320, successfully ditched in the Hudson River near New York City after takeoff from LaGuardia Airport. The aircraft was disabled by striking a flock of Canadian Geese and lost thrust in both engines during its initial climb out after takeoff. All 155 occupants safely evacuated the airliner. The NTSB cited the excellent crew resource management, safety equipment, and fast rescue response from ferry boat operators.
- *February 12, 2009*. Colgan Air Flight 3407, a Bombardier Dash 8, stalled and crashed on final approach to Buffalo, NY. There were 49 fatalities. The investigation revealed that the crew failed to monitor the airspeed in icing conditions and took an inappropriate response to the stick shaker stall alarm system, as well as failure to comply with the FAA Sterile Cockpit rule. As a result of the accident the FAA passed the Airline Safety and FAA Extension Act of 2010, which requires airline first officers to have an Airline Transport Pilot certificate. The rule essentially raises the experience level of new first officers, since the certificate requires 1,500 hours of total flight time experience unless certain strict educational conditions have been met.
- *April 2015, 2009*. Known as “Ash Thursday,” Iceland’s Eyjafjallajökull Volcano erupted, halting planes traversing the Atlantic Ocean. There were no fatalities, but it resulted in $200 million losses a day from cancelled flights and closures.
- *November 4, 2009*. Qantas Flight 32 had an uncontained engine failure on engine number two. The pilots received 54 computer messages alerting them of the failure. Pilots had to make an emergency landing at the Singapore Changi Airport. The failure was the first of this kind in the Airbus 380, one of the largest passenger aircraft.
- *June 1, 2009*. Air France Flight 447, an Airbus 330 from Rio de Janeiro to Paris, crashed into the Atlantic Ocean. There were 228 fatalities. The aircraft crashed in bad weather after receiving unusual airspeed indications from the plane’s Pitot Static System.
- *July 6, 2013*. Asiana Flight 214, a Boeing 777, was landing at the San Francisco International Airport. There were three fatalities resulting from the accident. The plane crashed short of the runway, with the landing gear and the tail striking the sea wall. NTSB experts found that the automation logic in the cockpit was not intuitive for the auto-throttle system, among other factors. Figure 1-5 shows the NTSB investigating the wreckage of Asiana Flight 214.

FIGURE 1-5 An investigator from the NTSB taking pictures of a landing gear from Asiana Flight 214 in San Francisco. (*Source: NTSB*)

- *March 8, 2014*. Malaysia Flight 370, a Boeing 777, departed Kuala Lumpur International Airport in Malaysia headed toward Beijing Capital International Airport. The flight deviated from its flight path and eventually fell off radar. As of 2016, the search for this plane is ongoing as its wreckage has yet to be found in the Indian Ocean.
- *July 17, 2014*. While crossing over Ukraine to Kuala Lumpur International Airport in Malaysia, Malaysia Flight 17, a Boeing 777, was shot down with a surface-to-air missile. There were 298 fatalities. The accident is covered in more detail in Chapter 14 of this book.
- *March 24, 2015*. Germanwings 9525, an Airbus 320, flying from Barcelona, Spain, to Dusseldorf, Germany, was deliberately crashed in the Alps by a suicidal pilot. There were 150 fatalities. This crash has raised questions about examining and treating mental health issues for pilots and is covered in more detail in Chapter 14 of this book.

Despite numerous accidents throughout the decades, there have been small

Despite numerous accidents throughout the decades, there have been small milestone improvements in aviation safety along the way. In 1965 the FAA stipulated stricter aircraft evacuation standards. Five years later, Congress enacted the Occupational Safety and Health Act (OSHA), which governs workplace health and safety in both the federal government and private sector. The purpose of OSHA is to make sure employees are working in an environment that is free of hazards such as toxic materials, mechanical dangers, excessive noise levels, and unsanitary conditions. Although this act is not aviation specific, it did focus the attention of the entire United States on safety and helped create awareness of the need for continuous improvement in commercial aviation safety, among other industries.

MEASURING SAFETY

Since safety is a broad term encompassing many facets, it is easy to be left wondering just how professionals quantify whether or not something is safe. It turns out that measuring safety is actually a difficult task. Although at first glance it may seem that accidents are an obvious way to measure safety, we should think twice. Does the fact that a company has not had an accident in the past 5 years mean that it is safe? If you are tempted to answer yes, consider that the company could have an accident tomorrow. If it does have the accident, does it mean that the company was not safe today? The question comes up constantly when safety managers attempt to justify the cost of certain initiatives that are being recommended, only to be met by the skeptical questions of those controlling the finances of an airline.

Often such leaders will look at a safety manager and ask, “Can you prove to me that this initiative will prevent an accident?” The answer to such a question, in short, is no. There is no way to prove such a relationship because if the initiative works it will prevent the confirmatory evidence from being produced (there will be no accident). In the safety business such a conundrum is called “trying to prove a negative.” How in the world would one go about producing scientific evidence to prove a negative? The people controlling the purse strings want hard data that show the money they are investing will achieve a certain payoff, whether that be in terms of lives saved, dollars preserved, or safety improved. In reality, improving safety is hypothetical with usually no hard evidence to justify initiatives, particularly when the ideas are based on non-accident data. The result is that it is often an arduous task to convince others of the monetary trade-off needed to implement a safety improvement.

The challenges of measuring safety notwithstanding, it is certainly desirable

to do so, and safety mangers speak in terms of *Safety Performance Indicators*, or *SPIs*. Such managers use SPIs to get a quantitative feel for how healthy the safety of their operation is at any given time, to measure whether safety is improving or deteriorating, and to compare safety in different segments of a given operation. When properly designed and measured, SPIs can provide the following data:

- Early warnings that a serious incident or accident may be around the corner
- How often preset limits are breached or how often they are almost exceeded
- How willing are employees to complete and submit voluntary safety reports
- The frequency with which specific events are occurring
- The effectiveness of new strategies and policies
- Different benchmarks for current practices in order to measure future initiatives

Measuring safety can paint either a big picture view of what is going on in an organization or a micro view of performance, sometimes down to the individual level. Both depictions are useful for trying to understand what is going on in an organization.

However, do SPIs capture all the data necessary with which to make decisions when managing a safety program? What is missed? Figure 1-6 shows an example of a cavalier approach toward safety that sometimes never gets noticed but which can cause significant problems. In the figure, a catering agent at a major airport is seen jumping between a truck and the galley door of an aircraft. The agent was in a rush and had parked the truck at an inappropriate angle and did not realize the misalignment until she was attempting to walk across the ramp from the catering truck to the aircraft. Instead of taking the time to repark the truck so that the ramp and handrails could be properly placed to safely walk between the truck and the jet, the catering agent instead chose to leap back and forth, numerous times, as the jet was serviced. A small misstep could have resulted in a fall to the ramp some 20 feet below, severely injuring if not killing the agent and anyone on the ramp during the event. In the picture the aircraft and catering truck symbols have been removed to protect the identity of the operators.

FIGURE 1-6 An aircraft catering agent is seen leaping over a large gap between the plane and the ramp. This is not a practice of good safety! (*Source: Authors*)

REACTIVE, PROACTIVE, AND PREDICTIVE SAFETY

One of the key learning outcomes for anyone attempting to learn modern commercial aviation safety is to recognize the shift in philosophy for how safety is managed. The philosophy is anchored in the advice proffered by many parents to their children, “An ounce of prevention is worth a pound of cure.” The question applies particularly well to how we face hazards as aviation professionals. Are we going to just cope with hazards as we become aware of them, or is there a more comprehensive approach for managing all the hazards

that take aim at our operation? But how do we, as aviation professionals, follow such a philosophy on a day to day basis? The execution of the idea proves far trickier than the concept itself.

All of us generally face aviation hazards actively. We recognize safety threats when they appear and do something to either avoid or mitigate the hazard. That type of active safety is pretty obvious and straightforward. For example, pilots may visually detect a weather buildup on climb-out and opt to make a 20 degree heading change to avoid the buildup. So, we use active safety all the time, but it is only one of several dimensions of safety where we can address hazards. After the first accident of the Wright Flyer in 1908, we realized that active safety alone was insufficient to fully detect hazards to flights. Relying on rather limited human perception to detect hazards in the highly complex arena of aviation will let us down time after time. The relatively low accident rate of today is largely the result of investigators who studied accidents to determine previously unknown or underpublicized hazards and who then offered practical recommendations to prevent future mishaps.

Aviation is a dynamic industry, so we can never stay static in our processes. How we approach safety in this industry is a major part of adapting to and addressing hazards in the workplace. In the early days, knowledge and experiences were shared verbally. Word got around quickly, and everyone benefited from one aviator's "close call." Safety concerns were addressed as they occurred, a safety culture known as *reactive safety*. Today we operate in a much more complex environment with barely any time to share our personal lessons-learned with anyone beyond our crewmates, let alone a viable method in which to "get the word out." So if we do not have time to "hangar fly" or "socialize" as aviators, how do we get the word out to others so they do not have to learn lessons the hard way?

There are many programs developed for commercial aviation uses. The *Aviation Safety Action Program (ASAP)* and *Aviation Safety Reporting System (ASRS)* are similar programs that attempt to tackle the issue. Both programs entail written reports voluntarily submitted by pilots. ASAP is a *proactive safety* initiative promoted by the FAA and operated by each airline. ASRS is managed by NASA and is open to report submissions by all pilots, whether or not they are affiliated with an airline. Both programs are designed to capture hazards and errors detected by aviators to distribute that information throughout the industry so that all may benefit. ASAP and ASRS also provide safety managers with evidence of risk that may otherwise be invisible, so that risk management actions can be taken to improve safety. Aviation professionals make errors in all phases

of flight or maintenance, regardless of experience. The details of a particular error are far more valuable than the results gained by any punitive measures, such as bad marks on personnel records or punishment. Thus, a healthy safety culture enthusiastically encourages the reporting of errors and hazards in this program.

Another successful program is the *Flight Operations Quality Assurance (FOQA)*. This program uses the analysis of routine flight data to detect, measure, and mitigate hazards, while promoting the proper use of data for safety. It is about safety enhancement without the accident! In other words, much like ASAP, we do not have to wait for bad events to occur for us to learn how to prevent the events. The FOQA process entails aggregating data from multiple flights before processing that data through software to search for trends that point to unsafe underlying conditions, such as poorly designed procedures, normalization of deviance, or unsafe external conditions. Generally, there is no need to investigate the individual data associated with a particular flight. However, determining the cause of a trend may require evaluation of individual flights feeding that trend.

A third noteworthy program is the *Line Operations Safety Audit (LOSA)*, a nonpunitive, unobtrusive, peer-to-peer flight deck observation program that collects safety-related flight data during normal operations in order to assess safety margins and improvement measures. The purpose behind LOSA is to provide leaders with early warnings of systemic safety problems. Basically, it is a “safety” cholesterol check. It works by selecting and training highly qualified pilots to ride on flight deck jump seats during routine flights to record the threats encountered by aircrew, the types of errors committed, and how the crews managed those threats and errors in order to maintain safety. How crews manage threats and errors provides excellent insight into training and organizational culture.

The Line Operations Safety Audit observers also study how pilots communicate and coordinate actions with each other, with cabin crewmembers, with ramp agents, with air traffic controllers, and with airline dispatchers. LOSA observers can also perform a carefully structured interview to collect pilot input for safety improvement. Some benefits of using LOSA include systematically and scientifically identifying the strengths and weaknesses of normal operations, decreasing the frequency of undesirable events, assessing the quality and usability of procedures, detecting inappropriate techniques, identifying design issues with automation as evidenced through mode errors and aircrew use, and detecting normalization of deviance in the form of workarounds and shortcuts used by aircrew, air traffic controllers, and dispatchers.

Recently there is talk of evolving the philosophy past proaction and into the realm of prediction. *Predictive safety* is the investigation of potential hazards that do not yet exist, but that might cause damage the very first time they make an appearance. Some air safety investigators believe that predictive safety is a key missing dimension of hazard management. They claim that any successful effort to further lower our accident rate must attempt to attack hazards before they present themselves, in addition to relying on the active, reactive, and proactive dimensions of safety.

An example of predictive safety is addressing potential hazards that may emerge when a flight department starts operating a new type of aircraft. If the flight department is used to operating small aircraft and decides to purchase a larger aircraft, predictive safety may uncover that current snow removal practices at the airport where the aircraft will be based will not provide sufficient wingtip clearance from snow banks on certain taxiways now that longer wingspans are involved. Such a predictive determination allows the operator to work with the airfield manager to adjust snow clearing procedures prior to the delivery of the new aircraft.

Continuing with our example, let us discuss what could happen without the use of predictive safety. If the crew of the newly purchased aircraft launches on their first wintry departure and stops their taxi due to insufficient wingtip clearance, the hazard is managed through the use of active safety. If the same crew mistakenly taxies their wingtip into the snow bank, perhaps due to poor visibility, then we learn about the hazard through reactive safety. If the same crew notices the growing snow bank during a snow storm and reports that it does not yet pose a hazard but might do so to subsequent users of the taxiway, we are talking about proactive safety.

Many aviators operate only in the active dimension of safety. That is a truly important dimension, but it is just one of several. If safety managers want to take full advantage of resources then they should think across the entire spectrum of safety, including reactive investigations and proactive data feeds. Chapter 7 will discuss proactive safety in more detail, and Chapter 14 will discuss the emerging dimension of predictive safety, to include how artificial intelligence may be used to open up the full power of short-term predictive safety.

ASRS EXAMPLES

Everyone in the aviation community has the ability to affect safety. The examples below are taken from the ASRS and show that there are many players

in the safety value chain. These examples are provided throughout the book to illustrate safety issues in the actual words of those commercial aviation professionals who experienced a safety event. The italicized portions that follow are the actual words used by aviation professionals to report the situation that they faced and the outcome they experienced. Following each narrative there is a question posed to help the reader connect the report with the content of the chapter.

MAINTENANCE

Title: Hydraulic system: crossed pressure lines.

While troubleshooting the cause of two previous replacements of an A-319's hydraulic system reservoir pressurization manifold, a Maintenance Technician found that "criss-crossed" pneumatic pressure lines were preventing pressurization of the Blue hydraulic system.

After discovering that we were going to install [an A-319's] hydraulic reservoir pressure manifold for the third time, I decided to figure out why the … manifolds were not pressurizing the Blue hydraulic reservoir to 50 PSI. After a few hours of troubleshooting the problem, I found that the left engine [pneumatic] supply line in the left wheel well … was connected to a "tee" [fitting] in the line that supplies all three hydraulic reservoirs thereby bypassing the [pressurization] manifold completely and probably over-pressurizing the reservoirs.

The Blue system pneumatic supply line (going to the hydraulic reservoir) was connected to a "union" [fitting], which is the manifold supply connection from the left engine thereby never supplying pneumatic pressure to the Blue reservoir. So the lines were criss-crossed.

Both "B" nuts will fit on either connection and there is plenty of room for the lines to cross and not chafe on anything. It appeared that neither line had been replaced. … When an Airbus comes into the hangar, a low-pressure check of each Green, Yellow and Blue hydraulic reservoir's head pressure is performed using ground service air. Although the Blue reservoir's head pressure was above the 22 PSI that sets off warnings in the cockpit, it was not possible to increase the head pressure by applying service air to see if the reservoir pressurization manifold was functioning.

When the Blue head pressure did not respond, the thought was that the manifold was again at fault. The aircraft had been flying for some time with the lines crossed, but since the Blue hydraulic reservoir head pressure never went below 22 PSI, no discrepancies were noted. Maintenance history showed the aircraft did have hydraulic issues with the Green and Yellow systems oozing hydraulic fluid, but those discrepancies were probably caused by high reservoir head pressures from the crossed pneumatic supply lines.

Question for the reader: what are the ethical implications of not looking for the root issues behind recurring maintenance problems?

FLIGHT OPERATIONS

Title: After an unexpected "hard bank" resulted in a hard landing, an ERJ145 crew discovered that icing may have been the cause.

ATC … descended us to 2,000 feet and vectored us for the approach. We were having a little problem picking up the localizer; however, we finally got a strong signal before the FAF and decided to fly the approach. … The Captain called, "Visual" and I said, "Landing."

I tried to turn off the autopilot and had a hard time getting the autopilot warning off. The Captain called, "Speed." I had gotten slow by about 3–4 knots and we were about 200 feet off the ground. I said, "Correcting" and added power and had no issue from there. We crossed the threshold and I started my crosswind correction and that is when the airplane took a hard bank to the right.

The Captain and I did everything we could to get the airplane on the ground. The landing was hard but we decided that the plane was able to taxi in. We asked to hold short of the center runway to collect ourselves, talk to the Flight Attendant, and resume the taxi. "Rudder INOP" displayed on the EICAS during taxi in. We got to the gate and deplaned then started making phone calls to report the rudder and hard landing.

After that was done, a ramp agent came up and let us know that there was some limited wing damage. We both went outside to see and it was then that we saw a considerable load of ice built up on all leading edges and engine nacelles.

Question for the reader: how can pilots use the cabin crew as an extension of their senses outside of the flight deck?

Air Traffic Control

Title: A Boeing 737 was dispatched without fuel for an alternate airport. As the aircraft descended for landing through 4,000 feet, onboard weather radar detected thunderstorm cells.

Credit must now be given to the FAA for what is the best job by a controller I have seen in 19 years of military and civilian flying. The controller began by using a concise stream of descriptive communications to paint a picture of weather location, intensity, reported microburst activity, winds, and runway availability.

He then went on to describe various options available to us. At this point, the flight conditions were VFR, but we were maneuvering to avoid several Level 4 returns on our radar. To facilitate our situational awareness, the controller turned the lights on Runway 08 to their highest setting. … Our fuel was now 5,200 lbs. and Runway 8 appeared clearly in front and to our right. … The aircraft touched down on centerline approximately 1,100 feet from the threshold….

I knew instinctively that time was not on my side and every moment spent maneuvering at 2,000 feet with the fuel I had was quickly taking away options, and none of them were very good. This aircraft made it safely on deck due to the outstanding work of the FAA and the skills of the flight crew.

Question for the reader: what role does a flight dispatcher play in the safety value chain?

Ramp Operations

Title: A communications breakdown between the cockpit and a tug driver at a foreign location led to a pushback with no one in positive control of the aircraft

foreign location led to a pushback with no one in positive control of the aircraft—and to some soul searching afterwards by the involved flight crew.

The pushback began in a normal fashion. Engine start was uneventful until the after start flows were accomplished. At that point we experienced a problem with the left bleed air valve. … The MEL showed this as a return to gate item. At this point, I told the mechanic we needed to be tugged back in. His response sounded like he was asking us to release the parking brake; however, neither of us quite understood what he had said about the brakes. I asked him if he was asking us to release the parking brake, to which he responded, "Release parking brake." I released the parking brake and the tug operation commenced.

With the tug operation underway, I turned my attention to the logbook, thinking about how I was going to write up this problem. The First Officer put away the QRH and then was looking over the MEL, which listed restrictions about flying in icing conditions. What to me seemed like a few seconds after we began to be tugged, the First Officer rhetorically asked, "Where is this guy taking us?" As I looked up I saw the end of the paved ramp approaching rapidly and heard the First Officer say something about stopping the aircraft.

At that point we were both simultaneously on the brakes. … After leaving about 20 feet of skid marks on the ramp, the aircraft came to a stop with the nosewheel approximately 8 feet from the end of the paved surface … and without the tug connected!! After stopping the aircraft and shutting down the engines and trying to comprehend what had just happened, my next concern was the location of the mechanic and if he was okay. He was okay.

Although this mechanic speaks fairly good English, I was truly surprised at the level of communications breakdown that had just occurred. … He told me he thought I was telling him I was releasing the parking brake. Once we started rolling he did not tell us to stop, but instead simply unplugged his headset and got out of the way.

What lessons can be learned or relearned from all of this? First of all, this is a reminder of something we all know, that being tugged is an operation which requires someone to be monitoring the aircraft. Second, never assume anything. Since we never saw the tug pull away (it pulled away while we were in the books), and we were told to release the parking brake, we thought we were under tow. … Also, next time I have determined I need to do a return to gate, I will shut down the engines sooner. … We were so distracted by what was going on that neither of us thought of shutting down the engines, nor did it seem critical at the moment since we thought we were under tow. … Thank goodness no one was hurt, no metal was bent, and no careers were put in jeopardy, but we sure came darn close.

Question for the reader: what specific actions could the flight crew have taken to prevent such a situation?

Cabin Crew

Title: In the event that inebriated passengers manage to get through the boarding process, sharp cabin crews can prevent inflight disruptions by removing them before takeoff.

I was working as Flight Attendant #1 when Flight Attendant #4 informed me that there were 11 first-class passengers instead of the 10 listed on my final paperwork. I called out names on my list and matched them with all passengers except for one in seat 1X. She told me her name, which was also the woman's name in seat 1Y. So, I asked to see their boarding passes and 1Y handed me the one for her

connecting flight. … She said she didn't have the one for this flight.

I asked for her identification and verified that she was who she claimed to be. I then asked the person in 1X for her identification and she said she didn't have it. I told her she did or she wouldn't be on the plane. I called the Captain and he said she had better show some identification now or we were going to return to the gate.

She got out of her seat and stood directly in front of me and said quietly, "Oh, I'll show you something." She then very slowly lifted the flap of her purse and pulled out her identification. She was not who she claimed to be. I asked her if she had been drinking and she said, "Well yeah."

I had her sit back down because she was swaying and talking very slowly. I called the Captain again to inform him of the passenger being drunk and lying about who she was. He said the agents were meeting the plane back at the gate. … As the inebriated passenger exited the airplane she turned to me and said, "What a safe airline you run." I said, "We try to keep it as safe as possible. Good-bye."

Question for the reader: where did the safety system fail to allow this situation to occur in the first place?

CONCLUSION

Modern commercial aviation is considered an ultrasafe high-risk industry (USHRI) in that it manages to operate with a great degree of safety in a high-risk environment. Safety may not be an airlines' top priority, making money is, but safety has to be ever-present in order for an airline to be profitable financially. Since efficiency is often a natural byproduct of safety, a commercial aviation operator that pursues safety processes will often also gain in operational efficiencies. Safety philosophy is important to understand, not only because it underpins most of the contents in this book but also because safety processes are not necessarily obvious to the untrained.

Most commercial aviation professionals have come a long way from attributing negative effects to unknown powers, but some professionals around the world still see accidents as "acts of God." Doing so brings psychological comfort because it removes ties to the truth that most accidents are preventable and, therefore, that we have an ethical obligation and often the ability to prevent such tragedies.

Safety requires careful thought, analysis, and action. For example, the principle of multicausality, if not properly understood, can lead to "witch hunts" against certain people and short-sighted answers to what are always complex safety issues. Understanding multicausality is fundamental to grasp how accidents happen and therefore to break a developing chain of events before they result in tragedy. Every aviation professional should feel an ethical obligation to detect a growing accident chain and have the moral courage to intervene to break

the sequence before tragedy ensues.

Security and safety may sound like the same term but in reality are quite different since the factors that lead up to intentional acts of harm and the factors that produce accidents are quite different. Therefore, different approaches are required to prevent accidents than to prevent terrorist attacks.

The history of aviation safety is intriguing and is constantly changing to include the high-tech approaches used at this very moment. Over the past half century, commercial aviation has come to depend less on accident investigation and more on innovative measures to prevent accidents. We call it the evolution from reactive to proactive safety and we measure the progress through statistical analyses.

The next chapter will expound on accident theory by examining causal chains and types of causes, different models used to understand how the causes combine to produce accidents, the mysterious role played by luck in accidents and incidents, and the different types of hazards that can imperil safe operations.

KEY TERMS

ALARP
Aviation Safety Action Program (ASAP)
Aviation Safety Reporting System (ASRS)
Disaster Incubation Period
Flight Operations Quality Assurance (FOQA)
Line Operations Safety Audit (LOSA)
Multicausality
Predictive Safety
Proactive Safety
Reactive Safety
Safety Performance Indicators (SPIs)
UltraSafe High-Risk Industry (USHRI)

REVIEW QUESTIONS

1. What are several reasons why aviation professionals care about commercial aviation safety?
2. What are the four types of accidents?

3. In the scenario about the African airfield with crocodiles, what are some other ways of reducing risk that were not mentioned in the chapter?
4. Which safety misconception surprised you the most and why?
5. What do we mean by the expression, "blaming the victim syndrome"?
6. Explain the relationship between accident investigation and the media portrayal of accidents.
7. In aviation, what is the difference between an accident and an incident?
8. Do you think it is possible to further reduce the current accident rate in commercial aviation?
9. As aviation continues to grow globally, especially in countries with underdeveloped safety regulations and antiquated mindsets, how do you think the growth will affect commercial aviation safety worldwide?
10. How are ASAP, ASRS, FOQA, and LOSA contributing to aviation safety?
11. Imagine that you are a professional in the airline industry and you witness a catering agent leaping between a catering truck and an aircraft being serviced, placing herself at great risk. What would you do about the situation?
12. What are some instances in your life in which you have tried to make something safer but it turned out causing more harm than benefit?

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CHAPTER TWO

WHY DO ACCIDENTS HAPPEN?

LEARNING OBJECTIVES

After completing this chapter, you should be able to

- Explain the major concepts that underpin accident theory.
- Expose why models are used to learn about complex phenomena, such as aviation accidents.
- Draw a simplified version of Reason's "Swiss Cheese" model of accident causation, giving examples where appropriate.
- Discuss the SHELL Model of accident causation and its implications.
- Explain the five causal factors in examining the nature of accidents: man, machine, medium, mission, and management.

INTRODUCTION

In the first chapter of the book we explored different safety philosophies and the long history of safety improvements that have advanced commercial aviation to where it is today. Now that the reader has a foundation in the basic concepts of safety from the first chapter, but before we explore what we can do to ensure that commercial aviation continues to get safer, we must tackle one topic head-on.

We must explore exactly what we are trying to avoid through all the efforts, initiatives, and programs outlined in this book: accidents! Specifically, we must answer the pressing question of why are there accidents and serious incidents in the first place. As any military commander will tell you, understanding the enemy is a must before attempting to defeat him/her. In aviation safety, the enemy is the accident that could happen at your operation, and the more we understand how accidents and serious incidents occur then the better we can prevent them from happening.

Figure 2-1 shows a floating Boeing 737 which was operating as Lion Air Flight 904 in Indonesia. The Lion Air crew decided to go-around from an approach too late and ended up contacting the water. Fortunately all 101 passengers and seven crewmembers survived the accident, although survivors of such events often suffer great mental trauma and can have invisible scars that last a long time.

FIGURE 2-1 The floating wreckage and survivors of Lion Air Flight 904. (*Source: National Transportation Safety Committee, Republic of Indonesia*)

Given the safety record of today's commercial aviation industry, it proves startling to think that during the early stages of scheduled transportation from 1922 to 1925, one pilot was killed for every 10,000 hours of flight (Lacagnina, Rosenkrans, & Werfelman, 2002). Such a figure is particularly striking when we contemplate how in these modern days U.S. Airlines carry 2 million passengers each day, according to the trade organization Airlines for America. In the early days of commercial aviation, bad weather was a common factor in most fatal accidents as pilots would depart blind to the weather ahead. If flying conditions at their location and a few other stops along their route were favorable, they would take the risk and make the trip. After all, "the mail must fly." Unfortunately, this attitude probably resulted in quite a few fatalities. Weather continues playing a factor in aviation accidents today, but so do numerous other

factors such as fatigue, traffic density, distraction, and a lack of proper training or procedures.

Since the early days of aviation, safety concepts have continued to evolve and develop over the years as technology and thinking have become more sophisticated. Accident investigation traditionally focused on preventing accidents by concentrating on simple causation theories to determine what happened and why it happened after an accident had taken place. When we speak of preventing accidents by studying the causes of accidents, some air safety investigators refer to that as the *reactive safety*. It was traditionally the approach that was used as the primary means to prevent future accidents.

The main goal of accident investigations is to establish the probable causes of accidents and to recommend control measures. Because most aviation accidents involve a complex maze of diverse events and causes, classifying or categorizing these accidents by type or *cause* gets quite complicated and involved. Also, accidents that are similar may often require different preventive strategies, although at times a single solution can eliminate or reduce the rate of occurrence of a wide range of accidents. For example, ground-proximity warning devices addressed the wide range of issues involved with controlled flight into terrain accidents for jetliners and helped reduce its occurrence rate. Figure 2-2 shows the field portion of an accident investigation, which can take a large number of specialists into remote parts of the world to seek answers to what led to a crash.

FIGURE 2-2 Investigators examining the wreckage of Malaysian Flight 17. (*Source: Dutch Ministerie van Defensie*)

The NTSB classifies accidents by several methods, such as causes and factors, sequence of events, and phase of operation. While aircraft component failures and encounters with weather are easy to classify, failures due to human errors are harder to trace and to assign to discrete categories for classification. Accidents have multiple causes; hence developing causal categories is a difficult task. In a majority of the cases, each cause is independent of the others, and if one did not exist, the accident might not have occurred. This is known as the “chain of causation” and breaking one of the links in the chain through defense and control measures can frequently be sufficient to prevent the accident.

The purpose of accident investigation is to uncover pervasive, unrecognized causal factors of accidents. This can help prevent similar accidents from occurring in the future. Some aviation safety efforts around the world unfortunately still rely exclusively on accident investigation to help prevent future accidents, but progress is being made elsewhere. Since the middle of the past century, the decrease in accident rates for portions of the world’s airline

industry has prompted leading thinkers in safety to propose new, innovative risk prevention recommendations.

Such thinking is called *proactive and predictive safety* by some investigators and has become such a fundamental aspect of modern safety management in commercial aviation that the entire Chapter 7 in this book is dedicated to the topic. Proactive safety is part of an evolution in thinking that increasingly relies less and less on accident investigation and more on technology and voluntary reporting to detect hazards and control risks before accidents occur. Since commercial aviation accidents are relatively rare, other means for identifying short-term changes in safety are required. The goal of proactive safety is to use *non-accident* data for analysis and modeling to conduct a preemptive strike so that accidents are prevented by addressing root causes of hazards before they manifest themselves in accidents.

While incidents and accidents provide after-the-fact evidence that safety was inadequate, accident modeling *through data from non-accident sources* assists with understanding how accidents happen so that measures such as policy decisions or changes in the aviation operating environment can be taken to prevent potential hazards from materializing. The ultimate expression of this evolution in thinking is predictive safety, which is discussed as part of the future of safety management in Chapter 14 of this book. We can see a depiction of this evolution of safety theory in Figure 2-3 (i.e., mature aviation safety management practice is moving from Reactive to Proactive to Predictive stage).

Reactive → Proactive → Predictive

FIGURE 2-3 Trend in modern aviation safety management. (*Source: ICAO*)

Instead of reacting to accidents and punishing the guilty party for failure to act safely, modern safety thinking has become proactive and even predictive of where and when the next accident may occur if current trends continue. The *ICAO Safety Management Manual* has an excellent discussion on the evolution of safety thinking over the past 50 years.

Together with the evolution of the philosophy on how to find hazards, as shown in Figure 2-3, the general areas of focus have also evolved over the past century. From after World War II until the 1970s, safety experts focused on “technical factors” to solve aviation safety problems. As aircraft became more modern, the thinking shifted to *human factors* and resulted in the creation of crew resource management concepts to address aviation safety woes. Today the concepts of organizational factors and safety culture have been embraced as

important factors to consider using the latest safety management system tools. This evolution of aviation safety thinking is illustrated in Figure 2-4.

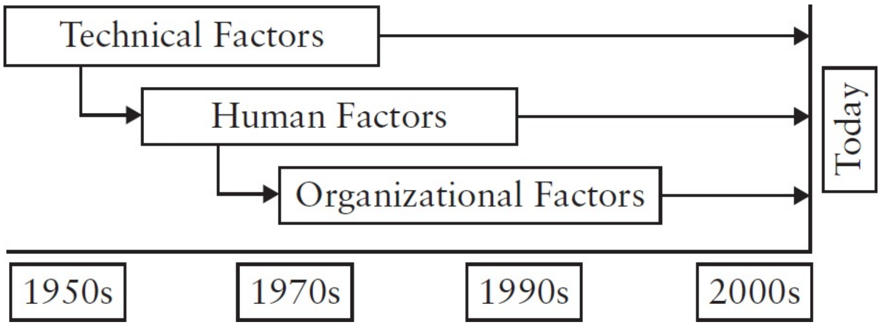

FIGURE 2-4 The evolution of safety thinking. (*Source: ICAO*)

At this point we should make a clarification. It is easy to feel like we are picking on aviation as we discuss accidents and safety, but in fact, other fields such as medical and maritime operations have similarly complex interaction of events that result in accidents and incidents. Safety thinking in these other fields has evolved in parallel to what has been witnessed in aviation. A clear example can be seen in the maritime industry. Ship designers must consider increasing demands for fuel efficiency, engine improvements, and new hull types in order to increase the safety of ships in the waterways.

The stakes are higher every day, and the serious implications of shipwrecks are just as grave as aircraft accidents. For example, if a container ship sinks or runs aground, the event can result in blocked shipping lanes, disruption of global trade, an environmental disaster due to leaking fuel or cargo, and bankrupt ship owners and insurance companies. To illustrate this, Figure 2-5 shows the 2012 capsizing of the Costa Concordia off the coast of Italian island of Giglio after striking rocks and creating a 50-meter gash on the port (left) side of the ship. The accident resulted in 32 fatalities and cost $570 million in damage to the ship, plus another estimated $2 billion and 500 workers to salvage the wreckage. As you can see from the example of this ship accident, it is not just aviation that deals with such complex events requiring constant safety vigilance.

FIGURE 2-5 The Costa Concordia as it commenced to list after running aground. (*Source: Italian National Civil Protection Department*)

DETERMINING THE CAUSES OF ACCIDENTS

Chapter 6 of this book will explore how accidents are investigated. This section explores the general aspects of accident causation and lays the foundation for understanding the contents that are to follow in the book.

Aviation accident theories have been developed by the ICAO, the NTSB, academia, and many other safety organizations that have traditionally sought to answer three interrelated questions after an accident:

- "*What* exactly happened?"
- "*Why* did the accident happen?"
- "How can we *prevent* future accidents?"

Determining *what* happened takes effort, but determining *why* a complex event such as an accident took place requires a great deal of skill and work. Once investigators determine *why* an accident occurred, which is always the result of

various factors, only then we can craft accurate recommendations that improve air safety. The process of accident science is one of investigation and action. Every time a recommendation is crafted and implemented, we have added to safety. One can think of the process as building a safety net over which commercial aviation flies every day. Over the decades we have added many threads to this so-called safety net, making the weave of the net tighter and tighter, and thus, making for increasingly safe and reliable air transportation. Searching for the answer to why an accident or serious incident has occurred is part of the larger question of human inquisitiveness. We need to understand the "why" of nature. Records left by the earliest civilized societies reveal that humans have always been interested in *causation*. Indeed, one can argue that the ability to reason about the causes of events is what enabled humans to create our modern civilization.

Reasoning about causation is a challenging undertaking. Perhaps this fact explains a strain of "anti-intellectualism" sometimes found in our contemporary society and as it has characterized societies of the past as well. To the extent that we avert our eyes from the difficult problem of causality, we become a little less human, more spectator than participant in life and society. Perhaps we are discomforted by what appears to the uninitiated as the elusiveness of cause and effect. Perhaps we somehow feel that explaining a mystery somehow diminishes it, that if we finally understand the cause of an event we will experience once again the let-down we felt as children when we finally saw through a magic trick or learned that Santa Claus and the Easter Bunny are figments of our parents' imaginations. However, we must avoid such inclinations in order to continue making progress as an enlightened civilization that relies on science and reason.

For thinkers in early Western societies, the study of causation seems to have been largely a matter of classification and systematic explanations. Around 350 BC, the famous Greek philosopher Aristotle declared that "every action must be due to one or other of seven causes: chance, nature, compulsion, habit, reason, anger, or appetite." Our own world, in contrast to the classical Greek world, is not so straightforward. Today's highly advanced technologies present challenges to thinking about causality which differ in vast degree, if not in kind, from philosophers of the past.

Not until the rise of early Enlightenment thinkers, people such as Copernicus, Galileo, Descartes, and Newton, did we see the clear beginnings of empirical inquiry and the so-called "scientific method." In our contemporary world, understanding the causes of *unsafe acts* in aviation requires analyses of highly complex and tightly coupled systems that involve complex interactions between

humans and machines. Such analyses rarely result in simple explanations of the complex problems which characterize aviation safety. In what follows, we discuss the implications of this fact.

COMPLEX PROBLEMS DO NOT HAVE SIMPLE SOLUTIONS

U.K. lecturer and author Edzard Ernst, a noted authority on safety in the practice of medicine, was the University of Exeter's first professor of complementary medicine. Ernst became famous among his students for starting his course in *Emergency and Operating Room Medicine* with the observation, "for every complex problem there is a simple solution … and it is wrong!" Perhaps he was inspired by the 19th century Irish writer Oscar Wilde, one of whose dramatic characters in *The Importance of Being Ernest* observes that so-called pure and simple truths are "rarely pure and never simple."

No doubt Professor Ernst wished to emphasize to his student that simplistic responses to complex circumstances are almost always lacking and can be inappropriate, especially when human lives weigh in the balance, as often is the case when doctors treat patients in an emergency rooms or on the operating table. The same logic applies to those charged with investigating aircraft accidents to prevent future tragedies.

Like emergency and operating room medicine, aviation is a profession where high reliability is required to safeguard human lives, and where the consequences of unsafe acts can be severe indeed. Professor Ernst would be the first to point out that seeking a simple and single reason for an aircraft accident usually involves the mistaken hope that a complex problem has a simple solution.

Nevertheless, society and the media that supposedly represent its interests, and indeed some aviation professionals as well, often seek simplistic explanations or even a single, simple cause for the tangle of unsafe acts and conditions that characterize aviation accidents. The well-known aviation writer Peter Garrison weighed-in on the complexities of determining causation in aircraft accidents:

> *I have written about the philosophical difficulties involved in the whole notion of determining the 'cause' of any event as complex as an aircraft accident. Some great thinkers have held that the connection between cause and effect is an illusion, but even without detouring through an epistemological Neverland we can easily see that many causal threads may be teased out of the knot of an airplane wreck, just as blame for a murder can be placed on the shooter, the victim, the abusive parents of one or the other, an overdose of cold medicine or gin, or a chronic shortage of affordable housing.*

In a similar vein, Jerome Lederer, one of the great leaders of the aviation

safety movement in the 20th century, observed that “a full discussion of causation analysis [in aviation accidents] could fill a book. The term ‘cause’ (or ‘causes’) is not well defined. There is an assumption that everyone knows what causes are. Wrong! There is little consensus. Causation analysis is highly emotional.”

An example of the complex nature of accident causation can be found in the Air France Flight 358 accident. Figure 2-6 shows investigators examining the wreckage of the Airbus 340 that overran a Toronto runway during landing after a flight from Paris in 2005. The investigating agency determined 14 findings as to cause, 12 findings as to risk, and 9 other factors which all formed part of the accident sequence. Edzard Ernst, Peter Garrison, and Jerome Lederer would likely point out that such a slew of factors are typical in most aircraft accidents, and anyone who focuses on just one element is doing a great disservice to the prevention of future accidents.

FIGURE 2-6 Accident investigators examining the wreckage of Air France Flight 358. (*Source: Transportation Safety Board Canada*)

Recommendations to prevent future accidents are crafted around the causal findings in a report, so not properly identifying relevant factors limits the amount of recommendations that are written, and thus, reduces the ability of the report to prevent similar factors from fostering future accidents.

ACTIVE CAUSES VS. ROOT CAUSES

In gardening there is an expression used to describe the process of loosening or removing the dirt that is around plant roots. "Teasing out the roots" refers to delicately pulling the roots free of the soil, often when transplanting the specimen or examining the full root structure in order to detect signs of disease or insect damage or problems involving caring for the plant.

Treating a sick plant by just examining the visible portion of a plant that lies above the ground can often lead to misdiagnoses, and thus, a faulty treatment plan. By carefully examining the root structure of a plant, gardeners get down to *root causes* of plant pathology, and as a result can produce accurate diagnoses of a plant's ailment and initiate effective treatments to bring the plant back to health. The gardening process serves as a very apt metaphor for how safety investigators relying only on the *active causes* of accidents will likely find their corrective efforts ineffective if the underlying causes are not addressed. They must seek out the *root causes* of the accident. Anyone who wants to understand why accidents happen must learn the concept of root cause analysis and realize that there is usually much more going on than what meets the eye at first glance in an accident.

CASE STUDY: WEST CARIBBEAN AIRWAYS ACCIDENT

Let us entertain an example to drive home such an important point. Figure 2-7 shows an MD-82 belonging to West Caribbean Airways, a company based in Colombia. That same tail number, operating as Flight 708, crashed in Venezuela in 2005 and resulted in 160 fatalities. The jet in the accident was flying at 33,000 feet when it stalled aerodynamically and the crew never recovered control, continuing in a stall all the way down from 33,000 feet to ground impact in the mountainous area of Venezuela near the Colombian border. At first glance it would appear that this was simply a case of pilot error, but labeling it as such and moving on neglects the numerous root causes that led to the pilot errors.

FIGURE 2-7 The pictured West Caribbean Airways MD-82 crashed in Venezuela after stalling at cruise altitude. (*Source: Wikimedia Commons*)

What may be some of the root causes for pilots not preventing and then not recovering from an aerodynamic stall? The airline had been undergoing significant financial stress, and the flight crew had not received regular paychecks in several months. In fact, the captain had been forced to work as a bartender just to make ends meet for his family. One can only imagine how the odd work schedule impacted the captain's fitness to fly and how the overall stress of dealing with the company's financial problems impacted the crew's ability to detect and react to the departure from controlled flight. However, the report did mention the poor decision making and poor communication between the pilots. The very next day after the accident the airline was grounded by the Colombian government agency in charge of regulating civil aviation.

By delving into the root causes of this accident, the investigators crafted a series of recommendations to address the root causes in order to not just prevent

the same type of accident as West Caribbean Airways Flight 708, but to prevent other vaguely related types of accidents. Among the recommendations proffered included the following:

- Ensure flight crews are trained in the proper use of performance tables for calculating the maximum operating altitude of an aircraft at a given weight and with different atmospheric conditions.
- Train airline flight dispatchers on how to calculate maximum operating altitude for different phases of flight.
- Require the training of flight crews on how to recover from stalls at high altitudes, versus just learning to recover from stalls in the traffic pattern environment as is typical in flight training.
- Regulating agencies should continue to assess the financial health of an airline after the initial operating certificate has been granted in order to ensure the maintenance and operational reliability of the certificate holder.
- Require flight crews of MD-80 type aircraft to review the autothrottle operation modes tied to the auto-flight system.

The recommendations of the report were written to address not just the active causes of the accident but also the root causes. The active cause may have been the pilot maneuvering the aircraft outside of its airspeed envelope. However, if a safety investigator cites only this cause, very little can be done to prevent a recurrence of the situation. In contrast, if the investigator discovers the root causes behind the pilot’s actions, a long-lasting intervention may be created. Perhaps the pilot was never trained on the specifics of how the performance ceiling is affected by fuel weight or by the use of anti-icing systems. Perhaps no quick reference material was available in the cockpit to allow for determining the boundaries of the airspeed envelop. Of course, a good accident investigator would also seek the reasons for those causes.

At this point the reader may be asking, what exactly does *root cause analysis* mean? For that matter, what exactly is a *cause*? Before delving into the different types of cause we see in aviation, let us explore what exactly is a “cause.” Although academia, government, and industry have wrestled with defining causation, the U.S. Air Force has produced excellent guidance on causation theory and has unfortunately a very long history of experience in accident investigation. Accordingly, an accident finding can be considered a “cause” if it is (1) an act or condition that singly, or in combination with other causes, resulted in the damage or injury that occurred, (2) a deficiency that, if corrected

or eliminated or avoided, would have likely prevented or mitigated the accident damage or significant injuries, or (3) an act, an omission, a condition, or a circumstance that either starts or sustains an accident sequence.

This discussion paves the way for us to exclude the following items from being a "cause":

- When a person's performance was reasonable given the circumstances (something we call the *reasonable person concept*)
- If it was a natural or reasonable outcome of the situation
- If entering the hazardous situation could not be reasonably avoided

If the definition of a cause is examined carefully, it can be argued that some causes are more obviously linked to an event than others; yet all remain causes of an event regardless of how close they appeared to be to the event. This linkage is called the *event chain* or the *error chain*. Over the past few decades, investigators have shown that accidents always have more than one cause, and that some causes are often outside of the direct control of the pilots involved in an accident.

Accident investigators aware of the multicausal nature of accidents seek to uncover all the major errors that led to the mishap. Many of the errors are usually found at the pilot level, but not all. A pilot's behavior is partly the result of the training invested in him or her, the procedures that have been created to follow, and the safety protocols built into the system that supports the operation of the aircraft. For example, the error chain for a wind-shear accident may look something like this:

Unforecast weather

+ Inadequate wind-shear detection

+ Insufficient wind-shear training

+ No hint of wind shear on the airport information system (ATIS)

+ No warning from air traffic control

+ Crew complacency

= Accident

An experienced investigator can pick apart each of these factors and ask all the "whys" of each until a comprehensive picture of all the failures is seen and corrective actions can be recommended. Each link in the sequence by itself may

not bring down an aircraft, but the likelihood of an accident increases with each "link" added to the chain.

Figure 2-8 shows several accident investigators discussing the wreckage of a UPS aircraft that crashed in 2014 when the crew failed to monitor altitude during an approach and impacted terrain approximately 3,300 feet short of the runway threshold in Birmingham, Alabama. Such investigators must methodically and patiently reconstruct the links in the chain of events that produced the accident.

FIGURE 2-8 Investigators discussing factors associated with the crash of UPS Flight 1354. (*Source: NTSB*)

In the case of this accident, several such links proved to be (1) the failure of the pilots to properly program the flight management computer, (2) a breakdown in communications between the pilots, (3) a mental bias about the expected weather, (4) reduced situation awareness from one of the pilots not making the required callouts during the approach, and (5) human performance deficiencies that prompted the crew errors in the first place. Investigators then had to dive

into each of those active causes to determine why they had been present in the first place. In other words, they had to perform a root cause analysis.

How do investigators distinguish active causes from root causes? When do they know that their root causal analysis has penetrated sufficiently back in time to extract the underlying issues that helped create the accident? We must distinguish between causes that are within the immediate control of a pilot or other frontline operator, and those that lead frontline operators to make a mistake in the first place.

Simplistically speaking, active causes are obvious, and root causes are hidden. *Active* causes are sometimes termed *proximate* or *apparent*. Alternative terms for *root* causes are *enabling* and *latent*. Most important, though different segments of society use different terms for obvious and hidden causes, all actionable causes come from those individuals who, whether they acted on the flight deck or from afar as support workers or managers, had an opportunity to do something to prevent the accident. Unsafe acts performed by someone who had a chance to prevent an accident through direct action, people such as dispatchers, air traffic controllers, aviation maintenance technicians, and pilots, are commonly associated with active causes. If someone who could have intervened to prevent an unsafe act or situation fails to perform, such as people in management or support functions such as a chief pilots, dispatch directors, air traffic control managers, or technical manual writers, their actions or failure to act constitutes a root, enabling, or latent cause.

In other words, root causes are usually conditions that facilitate errors by frontline operators but which are outside of the direct control of frontliners. Some like to say that root causes "set operators up for failure," that is, present operators with the opportunity to perform unsafe acts. This distinction, valid though it is, must not distract our attention from the notion that frontline operators are always directly responsible for safety, regardless of the support that they may be given or denied. Of course, the reality of the matter is that all aviation professionals share in the responsibility to provide reliable service, which means that all are on the hook to promote efficiency and safety.

A safety investigator often starts with active causes and must work backwards to discover the root causes underlying each active cause. The process continues until organizational fixes can be recommended to prevent similar or related mishaps from occurring. It can be tricky for investigators to cite root causes in formal accident reports, since there may be only a tenuous or even speculative link between the root causes and the active causes that are engendered by them. Since root causes often result from management breakdowns, it becomes particularly delicate to formally establish root causes without some type of firm

proof. In the world of causation, such proof can be very challenging to establish. Here are some key points about root cause to consider when differentiating them from active causes:

- Almost all accidents are “multicausal,” meaning that more than one cause produced the event. If we only focus on a single cause, then it will usually involve the pilot, who might be dead and cannot do anything to prevent a future accident.
- Effective investigations are those that provide recommendations to deal with the root causes, since those are the recommendations that can best prevent other accidents. Recommendations crafted around active causes usually often just deal with the crew and thus often will not prevent future accidents.
- Since accidents result from more than one cause, it is often suggested that we should not prioritize the causes. Nevertheless, people often want to know what the “primary” or “trigger” cause was for an accident. Avoid using such terms because often, if we point to a “primary cause,” that is where the recommendations and funding will go to prevent future similar accidents. However, since accidents are multicausal, removal of *any* of the causes will have the effect of preventing future accidents.

CASE STUDY: SKID AIRWAYS HYPOTHETICAL

To illustrate our discussion of active and root causes, what follows are the “findings, causes, and recommendations” arranged in chronological order for a hypothetical accident sequence involving a made-up airline named “Skid Airways” operating a 400 Series Boeing 737 during the summer of 2016:

> *Finding 1*. In January 2006, the FAA issued a B-737-400 Airworthiness Directive (AD) requiring weekly inspection of electrical wiring associated with the warning circuits for the forward cargo fire detector.
>
> *Finding 2*. The last time the evacuation slides were inspected for the accident aircraft was by the aircraft’s previous operator in 2011.
>
> *Finding 3 (ROOT CAUSE)*. As of March 2015, Skid Airways had not implemented a maintenance procedure for complying with the AD.
>
> *Finding 4 (ROOT CAUSE)*. As of March 2015, the Skid Airways aircraft maintenance training program did not teach the time intervals for inspecting

aircraft evacuation slides.

Finding 5 (ROOT CAUSE). As of March 2015, the Skid Airways inflight training department did not teach flight attendants to ensure each slide has inflated prior to evacuating passengers.

Finding 6 (ACTIVE CAUSE). Skid Airways mechanics never accomplished the required inspection of the electrical wiring associated with the fire detectors.

Finding 7 (ACTIVE CAUSE). Skid Airways mechanics failed to inspect the aircraft evacuation slide at the required interval.

Finding 8. At some point prior to the accident flight on June 11, 2016, an electrical short occurred in the warning circuits for the forward cargo fire detector.

Finding 9. On June 11, 2016, a Skid Airways B-737-400 departed on a FAR Part 121 passenger flight.

Finding 10. Shortly after becoming airborne the aircraft's forward cargo fire warning light activated, although no fire was present in the forward cargo bay.

Finding 11. The pilots assumed the fire warning was accurate and correctly performed emergency checklists for the cargo fire but the warning persisted.

Finding 12. The pilots coordinated with dispatch, ATC, and the cabin crew for an emergency return to landing.

Finding 13. The aircraft landed over maximum landing weight and the pilots applied maximum braking to attempt to stop within the runway remaining.

Finding 14. The aircraft overran the available runway, the pilot stopped the aircraft in a grass field past the end of the runway, and directed an emergency evacuation of passengers.

Finding 15 (ACTIVE CAUSE). One of the aircraft evacuation slides failed to inflate.

Finding 16 (ACTIVE CAUSE). The flight attendants failed to notice that the slide did not inflate.

Finding 17 (normal result of Finding 16). The flight attendants did not direct evacuating passengers away from the failed slide.

Finding 18. A passenger was fatally injured during the ground egress by falling off the slide that did not inflate.

Finding 19. A brake fire commenced in the left gear well due to heavy braking action during the landing.

Finding 20. The aircraft wing fuel tank exploded due to the brake fire.

Finding 21. The aircraft sustained severe damage due to the ensuing fire.

Recommendation 1. FAA Principal Maintenance Inspectors (PMIs) will ensure all air carriers operating B-737-400 are in compliance with the AD.

Recommendation 2. FAA Principal Operations Inspectors (POIs) will ensure all air carrier flight attendant training programs teach slide inspections as part of evacuation procedures.

Recommendation 3. FAA PMIs will ensure all air carrier maintenance programs teach how to inspect slides and respect inspection intervals.

This hypothetical example makes the point that an improperly performed root-cause investigation could have called the pilots causal for landing overweight when there was no actual fire and also causal for the injury stemming from the unnecessary evacuation, and the flight attendants causal for not ensuring slide deployment. If an improper investigation had taken place, all those misplaced causes would do very little to prevent future accidents, which we must remember is the whole reason for performing an accident investigation in the first place. Instead, the hypothetical example depicts a properly conducted accident investigation, to include a root cause analysis, and recommendations that will go a long way toward preventing future accidents.

As discussed earlier, recommendations are crafted around root causes so that we can prevent future accidents. In our hypothetical example, calling the pilots' decision to land overweight "causal" would be nonsense, since there was no way for them to know that the warning was erroneous. If we called the pilots causal for that, you can see that a recommendation written around that cause would be of no value and, in fact, could actually work against preventive safety because it was based on an erroneous conclusion.

USING MODELS TO UNDERSTAND ACCIDENT THEORY

The concepts exposed previously referring to *complexity*, causation, and root cause analysis are fundamental building blocks for understanding *accident theory*. The field of accident investigation, to include its theories, has sometimes been called the *accidentology*. The term is meant to connote that accident investigation is a scientific discipline that relies on concepts drawn from forensics, human performance, and data analysis. Although used in some countries, the term *accidentology* is not common in the parlance of investigators in the United States.

Scientific theories are confirmed explanations of how nature works. Accident theory is an amalgam of concepts that have gained acceptance by accident investigators and educators and which generalize our understandings of how accidents happen. Such a topic should not be taken lightly, since it entails the interaction of complicated variables to produce what is often great loss of life. Accident theory uses models to simplify complex concepts, and thus, make the concepts understandable for study and research. Figure 2-9 shows what remains of an aircraft following a ground evacuation and fire. Without resorting to models for understanding how such events take place it would prove extremely difficult to organize one's thinking in order to properly conduct an investigation of what occurred.

FIGURE 2-9 Wreckage showing evidence of fire and a ground evacuation. (*Source: U.K. Air Accidents*

Investigation Branch)

Throughout this chapter we refer to the relationship between complexity and understanding. As concepts become increasingly complex it is common to resort to models as a way of helping to understand how the concepts interrelate. They help us grasp “the big picture” so we can try to make sense of it all. We call the process “conceptual modeling.” Such modeling helps make sense of very intricate factors and helps show how the factors interrelate. Without modeling, the number of different variables and their complex interrelates would leave many of us confused, if not downright lost.

Since models are inherently attempts to simplify, they unfortunately come with a price. The price of simplification is that models can sacrifice knowledge of the nuances that are sometimes critical to getting the full picture of all the types of factors involved in an accident. What we have just described is also a fitting explanation of models: a knowledge construct that simplifies complexity. This chapter makes mention of popular aviation safety models, such as the “Swiss Cheese” and 5-Factor models.

To learn about accident theory we not only use conceptual models but we often arrange such models into visual representations to help us grasp their meaning more intuitively. Such a process is not just used to learn accident theory, as we use *visual conceptual models* all the time, particularly when attempting to learn new material composed of different interrelated factors.

For example, many of us remember learning about matter in chemistry by referencing a visual model of the atoms that depicted orbiting electrons, or we may remember learning about nutrition by referencing the visual model of the food pyramid that represented the optimal number of servings to be eaten every day from each of the basic food groups. Or perhaps we remember learning about a specific process by using an *if-then* style flowchart that guided us in different directions depending on how we answered certain questions. All those models are based on initially complex concepts that have been reduced down to primary elemental components and then visually depicted to understand how the concepts interrelate.

Aircraft accidents are extremely complex events caused by numerous interacting factors. Thus, it proves highly desirable to refer to visual conceptual models in order to understand *how* and *why* accidents take place. Such accident models:

- Help explain the relationship between hazards and accidents

- Assist with understanding and explaining reality
- Aid in visualizing things that cannot be directly observed
- Approximate conditions that exist in reality to be useful

There are several accident models discussed in the literature. Three models that have been most frequently associated with aviation are discussed next.

Reason's "Swiss Cheese" Model

Dr. James T. Reason started his career as a research psychologist with the Royal Air Force Institute of Aviation Medicine in the United Kingdom and with the U.S. Naval Aerospace Medical Institute in Florida. He later became a professor of psychology at the University of Manchester in the United Kingdom. It was during his time as a professor that he developed a visual conceptual model of accidents that has made a profound impact on accident theory.

James Reason's accident causation model was published in 1990 as a way to illustrate how human factors at various levels of an organization, such as an airline, can lead to accidents. The model is based on the concept that accidents have root causes that are often based on faulty actions or lack of actions at the management levels of an organization.

Reason's model of accident causation focuses on understanding incidents and accidents and their contributing factors. Reason's model is widely used in the aviation industry and has been recommended by various organizations, such as the FAA, for use in investigating the role of management policies and procedures in aircraft accidents. Reason's model traces the root causes of accidents to errors that occur in the higher management levels of an organization.

These errors are also referred to as *latent errors*. Reason contends that models are grossly inadequate if they attribute accidents solely to individual operator performance. Reason also proposes that human error is the end result rather than the cause of incidents or accidents. Today's technological systems involve complex and multiple interacting factors that are distant in time and proximity from the immediate circumstance of an accident.

A simplified depiction of the model is seen in Figure 2-10 and, upon visual inspection, many will instantly recognize why its visual appearance has led to it earning the nickname of the "Swiss Cheese" model. The holes in the layers of defenses make each layer look like a slice of Swiss cheese! A more detailed alternate depiction is provided in Figure 2-11 and shows bulleted ideas of what

may be considered when assessing how a particular defensive layer failed prior to an accident.

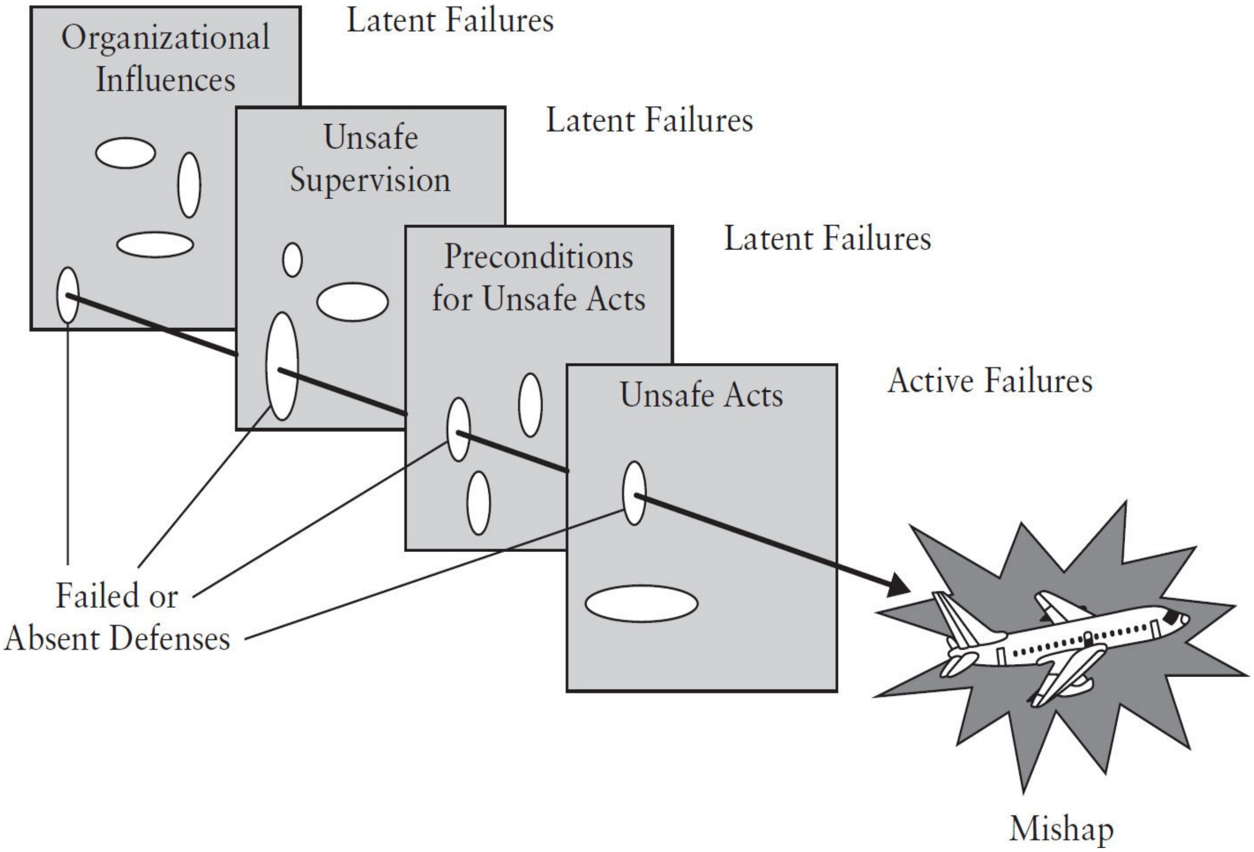

FIGURE 2-10 The *Reason's "Swiss Cheese" model and accident causal chain*. (*Source: Human error, 1st ed. Cambridge University Press, UK, 1990*)

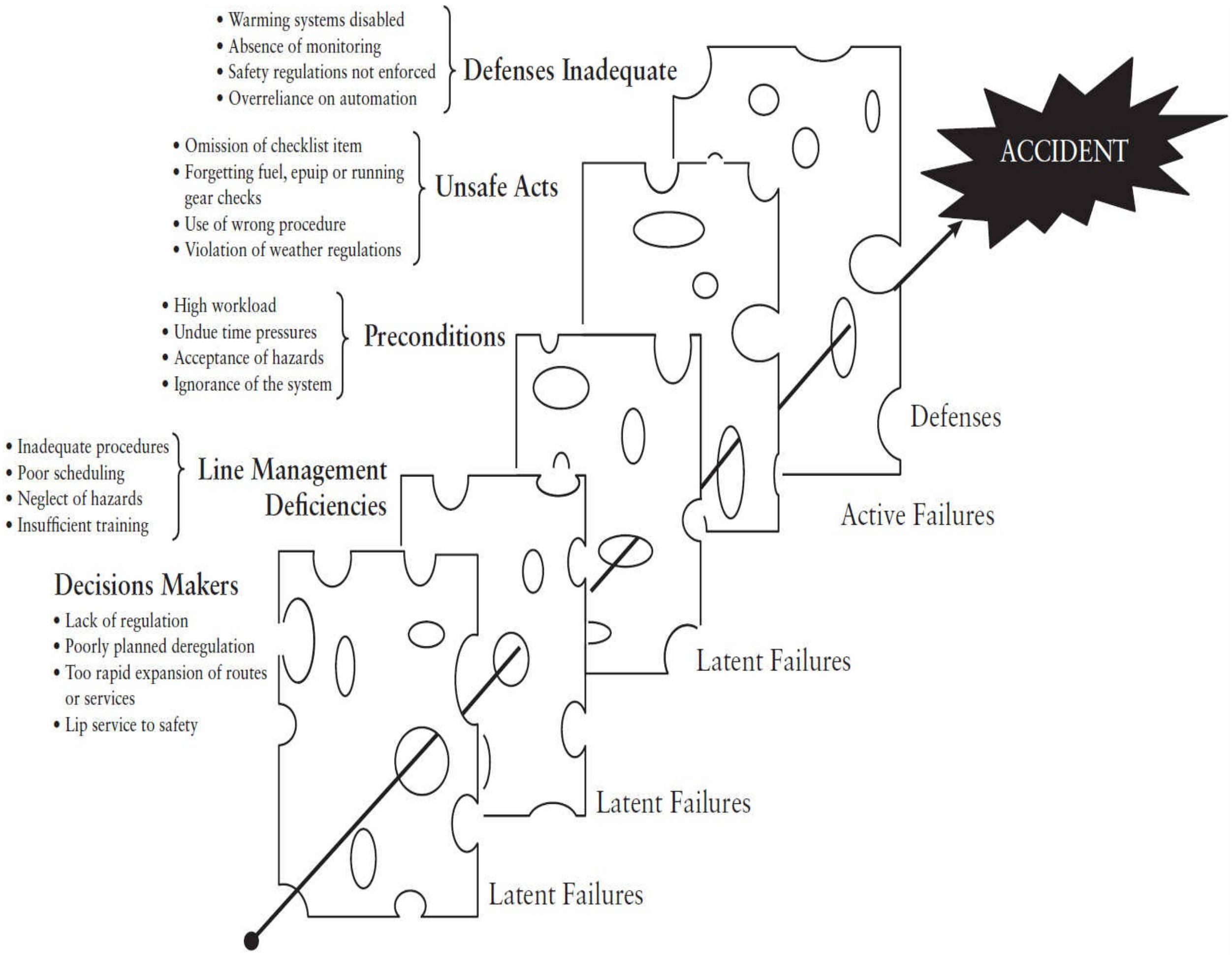

FIGURE 2-11 Alternate depiction of Reason's model showing possible underlying factors. (*Source: Alexander T. Wells and Clarence C. Rodrigues. Commercial Aviation Safety, 4th ed. McGraw-Hill, 2003; J. Reason. Human error, 1st ed. Cambridge University Press, UK, 1990*)

Reason hypothesized that most accidents can be seen to have one or more of four different levels of failure: at the organizational level, at the supervisory level, at preconditions that set humans up for unsafe acts, and the unsafe acts themselves. This model is a good representation of the complex relationship between the individual and the organization.

Reason explained that before an active human failure occurs, there are certain latent conditions in the organization which are the result of management action or inaction. He also stated that human error is the active “end result” rather than the root cause of accidents. Some of the important features of Reason's model are the following:

- Systems are protected by multiple layers of defenses that are designed to prevent hazards or system failures from cascading into accidents.

- Each layer of protection, however, can develop “holes” or flaws through safety deficiencies, resembling Swiss cheese.
- As the number and size of these holes in the defenses increase, the chances of accidents also increase.
- When the holes in each of the layers of defenses line up, an accident occurs.

The model recommends focusing on events beyond the *active failures* of frontline employees to latent preexisting conditions that result from fallible decisions made by high-level decision makers. It is these failures that permit active failures to occur. Management should build defenses by creating an organizational culture in which precursor events are detected and promptly corrected. Examples of real-world problems using Reason’s Swiss Cheese model would include the following:

Organizational Influences

- Rapid expansion
- Lack of regulation
- Management “lip service” to safety, where safety is said to be important but actions do not match the stated importance

Unsafe Supervision

- Risks and hazards neglected
- Poor work scheduling—fatigue
- Insufficient training

Preconditions for Unsafe Acts

- High workload
- Time pressure to perform tasks
- Ignorance of the system

Unsafe Acts

- Aircraft warning system disabled
- Omission of critical checklist item
- Overreliance on automation

Another way to depict the complex relationship of the organization and

human factor is provided in the *ICAO Safety Management Manual*. Consistent with Reason's model, various "screens" or defenses can be set up to plug the holes in the "Swiss cheese" and thus prevent the accident. These defenses are controls built into the system by management to protect against the inevitable human error that cannot be completely avoided. Figure 2-12 shows that organizational factors could be either weaknesses (holes in the cheese) or strengths (preventative screens) that could serve as defenses or "safety nets" to prevent an accident situation.

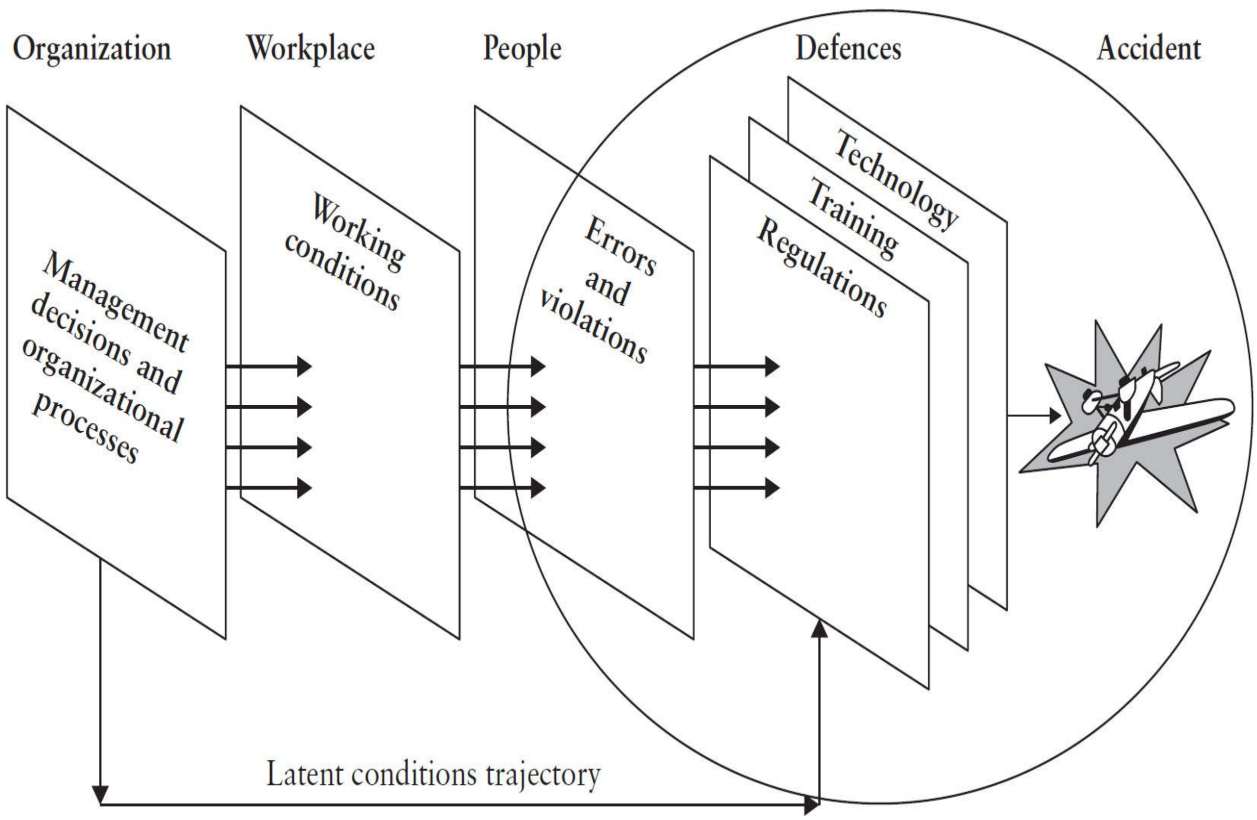

FIGURE 2-12 The Reason model of accident causation. (*Source: ICAO*)

Still another helpful model depiction to illustrate the importance of the organization and the dichotomy between latent conditions and active failures is provided in Figure 2-13. The top block represents the organizational processes which are under the control of management such as policy making, communication, and resources. These must be continually monitored and enhanced to prevent the organizational accident from occurring. Existing latent conditions can breach aviation system defense screens if not sufficient in the areas of regulations, training, and technology. Mitigation strategies should be developed to reinforce defenses to human errors. After the latent conditions and

defenses are bolstered, the organization should shift its focus to improve workplace conditions and thus contain the active “human errors” that always occur in any complex aviation scenario.

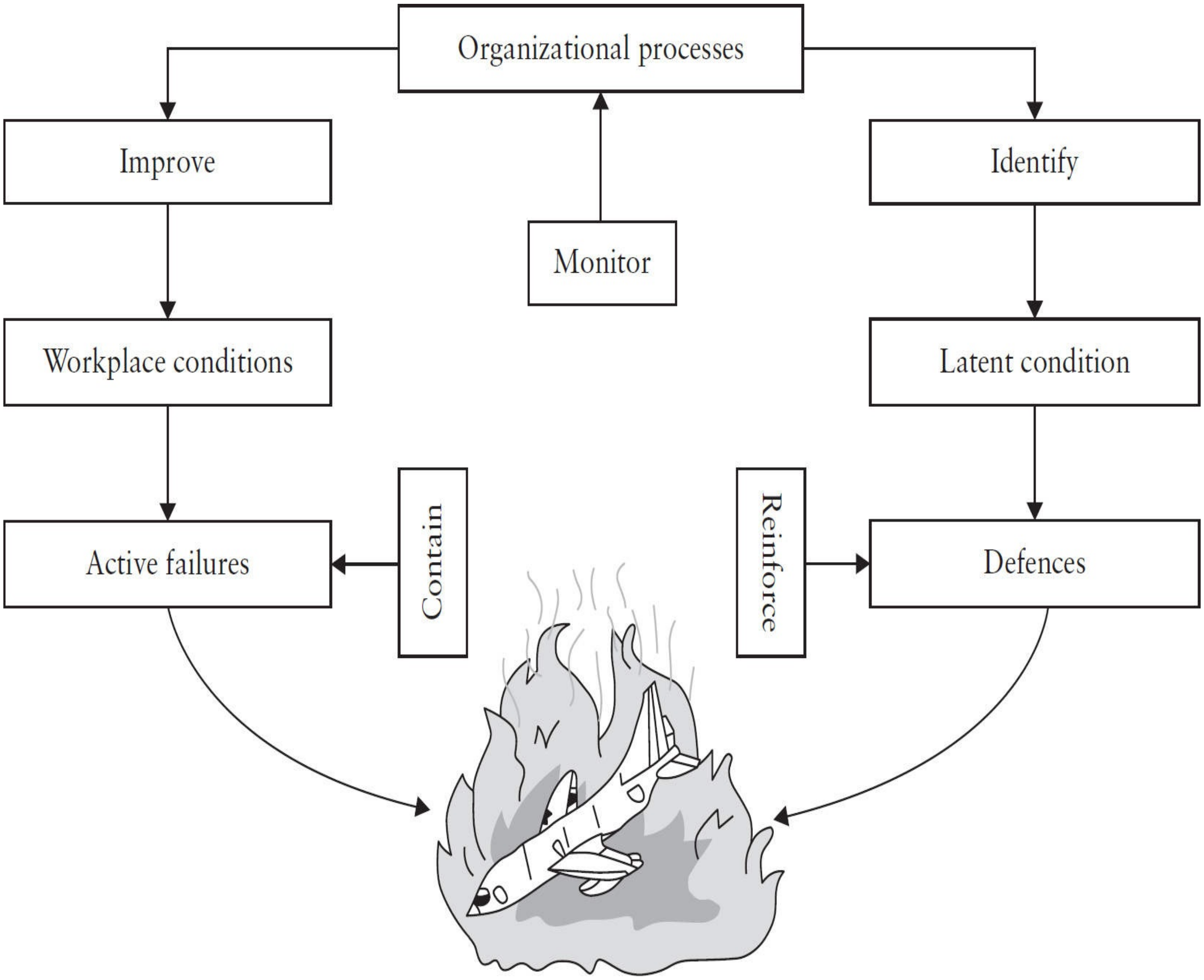

FIGURE 2-13 The organizational accident. (*Source: ICAO*)

SHELL MODEL

Another widely used visual conceptual tool in aviation accident theory is the *SHELL model*. This model can be traced back to work performed in 1972 by Professor Elwyn Edwards in the United Kingdom and a subsequent creation of a diagram by Captain Frank Hawkins in 1975.

As indicated by ICAO, the components of this model as identified in Figure 2-14 are as follows:

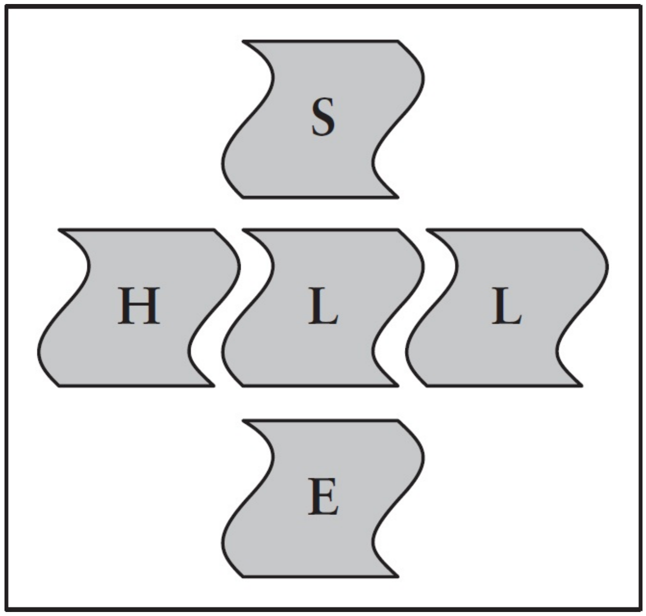

FIGURE 2-14 The SHELL model. (*Source: ICAO*)

- **S** = Software (such as procedures, checklists, and training)
- **H** = Hardware (machines and equipment)
- **E** = Environment (operating conditions)
- **L** = Liveware (human interface to S, H, and E above)
- **L** = Liveware (again, i.e., human to human interface)

To properly understand this model, it is important to note that the L (Liveware or Human Person) is always in the center of the diagram interacting with the other "SHELL" components. Since humans are inconsistent and do not interact perfectly with the other components, we need to consider four important factors affecting human performance (the so-called *"4 Ps" of human performance*):

- Physical factors (strength, height)
- Physiological factors (health, stress, etc.)
- Psychological factors (motivation, judgment, etc.)
- Psychosocial factors (personal issues or tension, etc.)

The SHELL interfaces are in constant interaction with each other and should be matched closely to the human element (Liveware) in the center of the system:

- *Liveware to Software*. This is the relationship between the human and

supporting systems found in the workplace. Not just computer programs, these include user-friendly issues in regulations, manuals, and checklists.

- *Liveware to Hardware*. This is the relationship between man and machine. Although humans adapt well to poor interfaces, they can easily cause safety hazards if not well designed.
- *Liveware to Liveware*. This is the relationship between the human and other people in the workplace. Communication styles and techniques are important here. Crew Resource Management (CRM) training has made great strides in this area.
- *Liveware to Environment*. This is the relationship between the human and the internal and external environments. Sleep patterns and fatigue are examples of important considerations here.

5-Factor Model

Another visual conceptual model is used to depict the major categories of factors that interact to create a safety error chain or an accident. This *5-Factor model* has become very popular in teaching accident theory and can prove helpful when studying the factors that contributed to any given accident. The *human, machine, medium, mission*, and *management* factors represent another valuable visual conceptual model for examining the nature of accidents, as represented by Figure 2-15. That is, when one seeks causal factors or preventive or remedial action, the diagram of the intertwined circles becomes a meaningful checklist for fact-finding and analysis to ensure that all factors are considered.

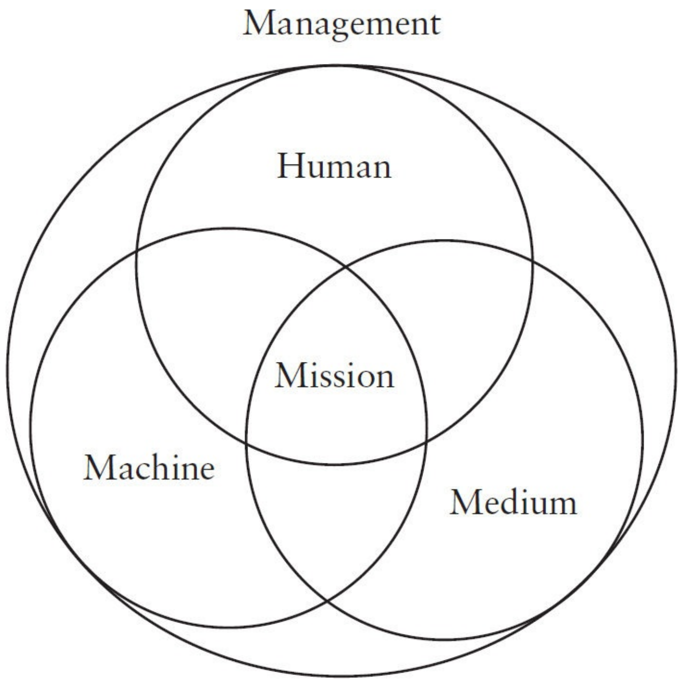

FIGURE 2-15 The 5-Factor model. (*Source: Authors*)

The five factors are closely interrelated and interact in numerous ways, although management plays the overall predominant role and is thus depicted as if hovering over the other factors. Mission is located as the central target or objective to emphasize that effective mission accomplishment is implicit in professional system (aviation) safety work.

Using this model brings to light a few issues that stem from the elements that comprise the 5-Factor model. First, there are internal and external factors that contribute to accidents. Internal and external issues are the two large categories of hazards, as there are things both outside and within the control of a person in the error chain. Second, there is a difference between technical and soft skills. Technical skills are teachable skill sets and professional knowledge that can easily be quantified, while soft skills relate to interpersonal skills and how people interact with one another. As we examine this model, you will see how these two large categories of skills come into play.

HUMAN. For several decades the model used to be called the "5-M" model because the word *man* was used instead of *human*. This edition of the book introduces the change in terms and therefore introduces the name "5-Factor" model instead of "5-M" model. The literature of aviation safety is peppered with references to the percentage of aircraft accidents that result from so-called "human error," that is, unsafe acts committed by humans. Some studies show the

percentage as 50%, some 75%, some as high as 80%. We believe even the highest of these percentages is too low. The figure may actually be very close to 100% for most aviation accidents.

If no unsafe act attributable to a human is apparent along the sequence of events leading to an accident or serious incident, then we may not have looked hard enough in the right places. Perhaps, for example, we have overlooked an error of omission committed by support personnel. While some may see the pilot as the only human in the system, others rightfully include all persons directly involved with the operation of aircraft—cabin crewmembers, dispatchers, ramp agents, gate agents, air traffic controllers, meteorologists, *etc.* In its widest sense, the concept should include all human involvement in aviation, such as in the design, assembly, maintenance, operation, and management of aircraft. Accident prevention must aim at all hazards, regardless of their origin.

As a result of refinements in technology and mechanical reliability over the years, the percentage of accidents caused by the category of *machine* has declined, while those caused by humans have risen proportionately. Because of this significant shift in the relationship between human and machine causes, a consensus has now emerged that accident prevention activities should be mainly directed toward the human and the organization in which the humans work. New flight deck technologies, for example, do not so much result in new ways to commit unsafe acts as to provide an opportunity for unsafe acts to experience a new way of expression. The unsafe acts remain the same while the interface and feedback loops provided by the technologies merely make their manifestations appear different. Figure 2-16 show the results of what can happen when such human–automation interaction go awry. The picture shows the debris field of a Boeing 777 that crashed into a seawall during landing at San Francisco in 2013 when the flight crew misused the autopilot and autothrottle during the approach.

FIGURE 2-16 The debris field for Asiana Flight 214. (*Source: NTSB*)

People are naturally reluctant to admit to their limitations for a variety of reasons, such as loss of face among peers, self-incrimination, fear of job loss, or considerations of blame and liability. When our personal performance does not meet our expectations, we are presented with an opportunity for improvement. However, such a situation requires a singular strength to capitalize on an opportunity to learn from our missteps. Seizing such opportunities constitutes what has been called *embracing our blunders*. Similarly, when we avoid blunders by learning from the missteps of others who have preceded us, we are *embracing the blunders of others*.

Some people simply dismiss missteps as examples of human fallibility, or take the cowardly position of covering up their actions or redirecting blame instead of learning from their embarrassing missteps. It takes courage to actively seek out and embrace shortfalls to foster improvement. It is not surprising, therefore, that information on the human-factor aspects of accidents or incidents

therefore, that information on the human-factor aspects of accidents or incidents is not readily forthcoming. This is unfortunate since it is often these areas that hold the key to the “why” of a person’s actions or inactions.

Perhaps it is only human to repeat foolish and dangerous behaviors, but it is certainly not inevitable. Sadly, when erring humans are air transport professionals, they subject not only themselves but also the traveling public to dangerous situations. In the past, the view that the human component of the 5-Factor model involved only the pilot led to the inappropriate use of the term *pilot error* as a cause of accidents, often to the exclusion of other human-factor causes. As a consequence, any other hazards revealed by an investigation were often not addressed. Further, since the term tended to describe only what happened rather than why, it was of little value as a basis for preventive action. Fortunately, the term is now increasingly in disuse by investigation authorities.

MACHINE. This component of the 5-Factor model refers to aviation technology and has made substantial advances over the years. There are still quite a few occasions when hazards are found in the design, manufacture, or maintenance of aircraft. In fact, a number of accidents can be traced to errors in the conception, design, and development phases of an aircraft. Modern aircraft design, therefore, attempts to minimize the effect of any one hazard.

For instance, good design should seek not only to make system failure unlikely but also to ensure that should it occur nevertheless, a single failure will not result in an accident. This goal is usually accomplished by so-called fail-safe features and redundancy in critical components or systems. A designer must also attempt to minimize the possibility of a person using or working on the equipment committing errors or mistakes in accordance with the inevitability of Murphy’s Law: “If something can go wrong, it will.”

To meet these aims, some form of a system safety program is often used during the development of a new aircraft type. Modern design must also take into account the limitations inherent in humans. Therefore, it includes systems that make the human’s task more efficient and that aim to prevent mistakes and errors. The ground-proximity warning system (GPWS) is an example of such a system. It has significantly reduced the number of accidents in which airworthy aircraft collide with the ground or water while under the control of the pilot.

The level of safety of an aircraft and its equipment is initially set by the airworthiness standards to which it is designed and built. Maintenance is then performed to ensure that an acceptable level of safety is achieved throughout the life of the aircraft. Manufacturing, maintenance, and repair errors can negate design safety features and introduce new hazards that may not be immediately apparent.

apparent.

As the service experience with a particular aircraft type increases, the maintenance program needs to be monitored and its contents developed and updated where necessary to maintain the required levels of safety. Some form of reporting system is required to ensure that component or system malfunctions and defects are assessed and corrected in a timely manner.

The reliability of a component is an expression of the likelihood that it will perform to certain specifications for a defined length of time under prescribed conditions. Various methods can be used to express reliability. A common method for electronic components is the mean time between failures (MTBF), and the reliability of aircraft power plants is usually expressed as the number of shutdowns per 100,000 operating hours.

Failures normally arise in three distinct phases in the life of a component. Initial failures, caused by inadequate design or manufacture, usually occur early in its life. Modifications to the component or its use usually reduce these to a minimum during the main or useful life period. Random failures may occur during this period. Near the end of the life of a component, increased failures occur as the result of its wearing out. Graphic representation of this failure pattern gives rise to the typical "bathtub-shaped" curve, as shown in Figure 2-17.

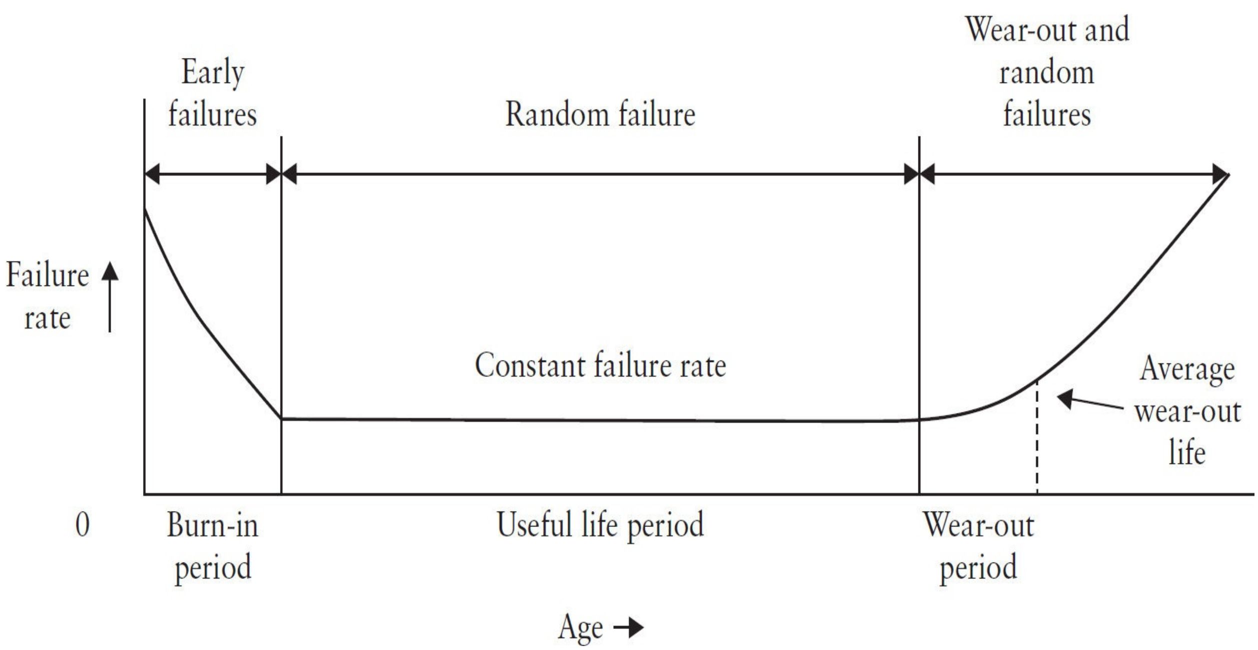

FIGURE 2-17 Aircraft system failure pattern. (*Source: Authors*)

The evolution of the machine component in the 5-Factor model has proved quite interesting over the past half century. In the period from 1970 to 1990, three generations of wide-body airliners appeared. The first generation,

introduced around 1970, was the wide-body, long-range airliner. Examples are the Boeing 747, the Lockheed L-1011, and the Douglas DC-10. These wide-body airliners were equipped with three to four high bypass-ratio engines, inertial navigation systems (INSs), and an automatic landing system (ALS). The flight decks of these airliners were equipped with many electromechanical instruments. These aircraft were flown by a flight crew of two pilots and one flight engineer.

The second generation, introduced around 1980, was medium to long range, wide-body airliners with a new digital avionics system. Examples are the Airbus 310 and the Boeing 757/767. These new wide-body airliners are equipped with an electronic flight instrument system (EFIS), a flight management system (FMS), and either an Engine Indicating Crew Alerting System (EICAS for Boeing) or an Electronic Centralized Aircraft Monitor (ECAM for Airbus). In greater detail, the EFIS, FMS, and EICAS/ECAM provide the following functions:

- The EFIS primary flight display (PFD) provides a combined presentation of attitude, flight director, instrument landing system (ILS) deviation, flight mode annunciation, and speed and altitude information on a single cathode-ray tube (CRT) display, thus reducing the scanning cycle required by pilots monitoring instrumentation.
- The EFIS multifunction display (MFD) or navigation display (ND) provides integrated map, horizontal flight path, weather radar, heading, and wind vector information, largely reducing the navigation task (in combination with the FMS) and improving the positional awareness of the pilot.
- The FMS provides integrated navigation and fuel management information, as well as a host of performance and navigation information, largely increasing the pilot’s flight management and navigation capabilities.
- The EICAS/ECAM provides the aircraft crew with engine and other system instruments and warning annunciations that also may depict the remedial action required. The “glass” cockpit is equipped with six-color CRT graphics display for the EFIS, as well as two alphanumeric monochrome control display units (CDUs) for the FMS; apart from the CRTs, a number of electromechanical instruments are still used to enable a safe continuation of flight in case all CRTs should fail. The introduction of the EFIS, FMS, and EICAS/ECAM allowed the elimination of the flight engineer from the flight deck, providing a significant cost reduction for the operations with this type of airliner.

The third-generation airliner, introduced around 1990, is a medium to long range type of aircraft with a revolutionary new digital flight control system, no longer using mechanical links between the pilot’s control yoke and the hydraulic actuators of the flight control surfaces. This *fly-by-wire* (FBW) technology allows for new flight control concepts and aerodynamic envelope protection systems. Examples of these new FBW airliners are the Airbus 320/330/340 and the Boeing 777. The engines of this new generation of airliners are controlled by *full-authority digital engine control* (FADEC) systems. On the flight deck, the CRTs are larger, and the number of electromechanical instruments has substantially decreased.

Aircraft used in modern commercial aviation have allowed the airline industry to develop into a reliable and economical all-weather transport system. Through the use of ever-improving aerodynamic designs and engine technology, as well as the increasing use of lightweight composite materials since 1970, the fuel consumption per passenger-mile has been reduced by more than 30%. Radio navigation and approach systems, inertial navigation systems, weather radar, and ATC, in combination with ever-improving training and standardized procedures, allow safe flight, also in reduced-visibility conditions.

The accident rate for the newer generation of airplanes, such as the Boeing 757/767 and Airbus 310/320/330, is considerably better than that for earlier designs. It is reasonable to expect that the current new models, such as the Boeing 787 and Airbus 350/380, will be safer as a result of more sophisticated design and applied technology.

New technology will be available to the flight crews and controllers during the next decade, prompting further enhancements in the machine component of the 5-Factor model through the following developments:

- Better weather detection systems will provide information to airline dispatchers and pilots, allowing more efficient and safe flight around weather systems, both en route and near the airport.
- Global Positioning Systems (GPSs) are widely being used now but will become the primary source for navigation and surveillance information, replacing ground-based, line-of-sight-limited navigation facilities and radar facilities. GPS will also be the primary means of guidance for precision landings and departures at our nation’s airports under the new Next Generation (NextGen) Air Traffic Control concept.
- Improved air traffic control tools are already being installed in FAA facilities to give the controller more reliable and efficient means to see and

communicate with the airplanes under his or her control. Improved collision avoidance will be provided by the new Automatic Dependent Surveillance Broadcast (ADS-B) System.

- Flight decks will continue to improve, with added redundancy and integrated avionics giving the pilot more options and greater situation awareness.
- Data link will allow clearances, weather, and traffic information to be provided on the flight deck in a fast, error-free, digital form. One of the big advantages of data link will be the elimination of "read-back" errors between the pilot and controller.
- Human factors will be a major consideration from the onset of airplane design to ensure that the airplane can be operated and maintained easily within human limits.

Our aviation system has evolved over the past decades to serve a vital role in the economy and our way of life. The system is complex, built on international standards with rigid quality control in all areas from the cockpit to the maintenance hangar to the air traffic control facility.

MEDIUM. The *medium* (environment) in which aircraft operations take place, equipment is used, and personnel work directly affects safety. From the accident prevention viewpoint, this discussion considers the environment to comprise two parts: the natural environment and the artificial environment.

Weather, topography, and other natural phenomena are elements of the natural environment. Their manifestations, in forms such as temperature, wind, rain, ice, lightning, mountains, volcanic eruptions, and wildlife, with some exceptions are all beyond the control of humans. These manifestations may be hazardous, and since they cannot be eliminated, they must be avoided or allowances must be made for them.

Wildlife poses a major threat to safe flight operations. For example, if a jet engine ingests a piece of a bird or a plane strikes a deer, it can lead to a fatal crash. To protect our skies, 50 years ago the FAA began adopting a biological-ecological approach by partnering with the U.S. Department of Agriculture to develop wildlife management strategies. Such measures include keeping grasses at a certain level, trap and relocation efforts of animals, and eliminating standing water. Much of this effort is centered on airports and nearby areas since 70% of bird strikes occur at or below 500 ft above sea level, and many of these birds are species federally protected under the Migratory Bird Treaty Act. Furthermore, airports and airplanes can report strikes to help the FAA determine what kind of

wildlife is posing threats. Since we cannot eliminate the environment and its inhabitants, we must work around them.

Another environmental menace that is lesser known is volcanic ash. When ingested by an aircraft engine, the ash can form glass in the hot sections of the engine, block the cooling holes, prevent air flow, and cause damage to the compressor blades. If severe enough, it can cause the engine to lose power. Due to these concerns, manufacturers of aircraft engines all agree that under no circumstance should planes fly through a volcanic ash cloud due to the potential hazards. Unfortunately, there is no standard for measuring ash concentration in the air, and hazards may exist over 1,000 miles away. The eruption of Iceland's Eyjafjallajökull volcano in 2010 is a great example of how volcanic ash can paralyze the commercial aviation sector. As a result of this eruption, there were 17,000 cancellations a day, which resulted in $200 million loss a day, totaling $2 billion in all. However, this financial toll must be measured against what would have happened if the industry had lost an airliner to the ash.

The artificial portion of the environment can be further divided into physical and nonphysical parts. The physical portion includes those artificial objects that form part of the aviation environment. Air traffic control, airports, navigation aids, landing aids, and airfield lighting are examples of the artificial physical environment. The artificial nonphysical environment, sometimes called *system software*, includes those procedural components that determine how a system should or will function. This part of the environment includes national and federal legislation, associated orders and regulations, standard operating procedures, training syllabi, and so forth.

Many hazards continue to exist in the environment because the people responsible do not want to become involved in change, consider that nothing can be done, or are insufficiently motivated to take the necessary actions. Obstructions near runways, malfunctioning or nonexistent airport equipment, errors or omissions on aeronautical charts, faulty procedures, and so forth are examples of artificial environmental hazards that can have a direct effect on aviation safety.

One important point should be made. Many accidents that seem unpreventable due to factors in the medium category of the 5-Factor model actually are preventable, and others that occur because of a calculated risk can be reduced in number or severity by implementing appropriate risk-mitigating actions.

In modern aviation operations, each individual has a unique opportunity to break the accident chain of events, and passing up the chance may have serious

consequences. Complacency comes in many forms, but it always reflects an unprofessional attitude that fosters the growth of accident chains. A strong sense of *professionalism* creates the proper culture and motivation for appropriate action. Instead of remaining silent, true aviation professionals take responsibility for aviation safety through prompt reporting of hazardous situations. The responsibility to support safety by positive actions must be clearly understood by each member of the organization; it must be part and parcel of each member's sense of what it means to be aviation professionals.

MISSION. Notwithstanding the man-machine-medium concept, some safety experts consider the type of *mission*, or the purpose of the operation, to be equally important. Obviously the risks associated with different types of operation vary considerably. A small regional airline operating out of many small airports during the winter months in the New England area has a completely different mission than an all-cargo carrier flying extensive over-water flights to underdeveloped countries or a major carrier flying from New York to Los Angeles. Each category of operation (mission) has certain intrinsic hazards that have to be accepted. This fact is reflected in the accident rates of the different categories of operation and is the reason why such rates are usually calculated separately.

MANAGEMENT. The responsibility for safety and, thus, accident prevention in any organization ultimately rests with *management*, because only management controls the allocation of resources. For example, airline management selects the type of aircraft to be purchased, the personnel to fly and maintain them, the routes over which they operate, and the training and operating procedures used. Federal authorities promulgate airworthiness standards and personnel licensing criteria and provide air traffic and other services. Manufacturers are responsible for the design and manufacture of aircraft, components, and power plants as well as monitoring of their airworthiness.

The slogan "Safety is everybody's business" means that all persons should be aware of the consequences of their mistakes and strive to avoid them. Unfortunately, not everyone realizes this, even though most people want to do a good job and do it safely. Therefore, management is responsible for fostering this basic motivation so that each employee develops an awareness of safety. To do this, management must provide the proper working environment, adequate training and supervision, and the right facilities and equipment.

Management's involvement and the resources it allocates have a profound effect on the quality of the organization's accident prevention program.

Sometimes, because of financial responsibilities, management is reluctant to spend money to improve safety. However, it can usually be shown that not only are accident prevention activities cost-effective, but also they tend to improve the performance of people, reduce waste, and increase the overall efficiency of the organization.

Management's responsibilities for safety go well beyond financial provisions. Encouragement and active support of accident prevention programs must be clearly visible to all staff, if such programs are to be effective. For example, in addition to determining who was responsible for an accident or incident, management's investigation must also delve into the underlying factors that induced the human error. Such an investigation may well indicate faults in management's own policies and latent organizational procedures.

Complacency or a false sense of security should not be allowed to develop as a result of long periods without an accident or serious incident. An organization with a good safety record is not necessarily a safe organization. Good fortune rather than good management practices may be responsible for what appears to be a safe operation.

On the whole, management attitudes and behavior have a profound effect on staff. For example, if management is willing to accept a lower standard of maintenance, then the lower standard can easily become the norm. Or, if the company is in serious financial difficulties, staff may be tempted or pressured into lowering their margins of safety by "cutting corners" as a gesture of loyalty to the company or even self-interest in retaining their jobs. Consequently, such practices can and often do lead to the introduction of hazards. Morale within an organization also affects safety. Low morale may develop for many reasons but nearly always leads to loss of pride in one's work, an erosion of self-discipline, and other hazard-creating conditions.

THE ELEMENT OF LUCK

There is an old expression humorously used by aviators when referring to the role of chance in the outcome of flight operations: "It is better to be lucky than good!" The expression means that, despite an aviator's expert skills and knowledge, sometimes just plain and simple good luck saves the day. Of course, the opposite can also be true in the sense that bad luck can overcome the efforts of everyone contributing positively to a safety value chain and result in an undesirable outcome. At least that is what can appear to be the case at first glance, although more detailed inspection often reveals that bad luck is actually comprised of variables that could have been acted on by a human, at one time or

comprised of variables that could have been acted on by a human, at one time or another, in order to prevent the undesirable outcome. The element of luck is important to study in more depth.

We often hear motivation sayings that discount the role of luck in life. One explanation of luck as a positive force states that it is *preparation meeting opportunity*. Certainly the more prepared we are, the more likely we will be to produce a good outcome to an unexpected situation. Equally so, opportunities present themselves often and can couple nicely with preparation, as the quote implies.

One should notice that the term *luck* is often interpreted as being synonymous with good outcomes, whereas in reality luck can refer to influences that lead to a good outcome or a bad outcome. Luck, otherwise known as *chance*, has no purpose, is unpredictable, and uncontrollable, but yet can determine the outcome of an event both favorably and unfavorably.

What remains after our exhaustive attempts at controlling variables that impact aviation safety can be considered *luck*. The element of luck is rarely examined in traditional aviation safety literature. One possible explanation for such an absence of discussion about luck is that, by definition, we can do nothing to impact how luck affects the safety error chain, so some argue that any time devoted to studying luck is a waste of time.

The opposing argument is that safety professionals view the element of luck as producing a need to expect the unexpected and that we must therefore plan for the unexpected, whenever possible. Such safety professionals usually hear talk of helplessness at controlling luck and counter by saying, “Safety is about making your own luck!”

For those desiring an example of how luck plays a role in commercial aviation safety several cases can be found by canvassing accident and incident reports. A clear example is U.S. Airways Flight 1549 in 2009 which is popularly known as “The Miracle on the Hudson.” It was *bad* luck that Captain Sully Sullenberger and First Officer Jeff Skiles hit several large birds with their Airbus 320 during their climbout from New York City. The impacts resulted in the two aviators having to ditch their Airbus in the Hudson River.

It was particularly bad luck when one considers that the difference of just a few seconds in their takeoff time would have resulted in the flight missing the birds altogether. However, it was good luck that the aircraft hit the birds during the daytime and while in visual meteorological conditions, since doing so allowed the pilots to visually acquire the river and line the jet up for a safe ditching.

Another example of luck, also from the year 2009, is Emirates Flight 407

during its departure from Melbourne, Australia. It was certainly not luck but human error when the flight crew of the Airbus 340 programmed incorrect data into the flight deck automation, resulting in lower than necessary engine thrust for takeoff. When the aircraft was unable to climb it was arguably excellent luck when the flight subsequently only hit the strobe lights and localizer antenna at the end of the runway, cleared a building by only 20 inches, and then safely returned the aircraft for landing!

The conceptual models discussed in this chapter do their best to incorporate the large categories of factors that combine to create an accident sequence, but do not fully address the role of luck in the sequence and subsequent outcomes.

CASE STUDY: AIR FRANCE FLIGHT 4590

Figure 2-18 shows the stunning profile of a Concorde aircraft in flight as it used to be operated by Air France. On July 25, 2000, during takeoff on a flight from Paris to New York City, an Air France Concorde’s tire ran over a strip of metal that had fallen off another aircraft. As a result, debris was thrown against the Concorde’s wing structure and caused a fuel tank to rupture. Shortly after, a fire ensued and was fueled by the leak in the tank. The crew shut down engine number two, which was operating near idle power and noticed that the landing gear would not retract. For around a minute the aircraft was able to fly but was unable to gain height or speed. Engine number 1 eventually lost thrust, as did engines 3 and 4. The aircraft subsequently crashed into a hotel, killing 113 members on board plus 4 employees of a hotel on the ground. The French Bureau Enquêtes-Accidents (BEA) was the government agency that conducted the accident investigation.

FIGURE 2-18 A Concorde in Air France livery. (*Source: Wikimedia Commons*)

This case study is meant to illustrate the highly complex nature of accident causation to include the myriad factors that combine to produce a fatal sequence of events culminating in tragedy for all aboard an aircraft and even to some on the ground. As such we are all stakeholders in commercial aviation safety, since even if we do not fly, aircraft do fly over our heads, and history is filled with examples of how safety problems aloft can take a direct toll on the safety of those who feel that they are safely on the ground. This case study provides the findings, causes, and recommendations contained in the accident report, along with the mention of some of the processes used during the investigation. The reader is urged to think about the previously exposed visual conceptual models contained in this chapter while reading through the case study.

It bears noting that another airline played a role in the sequence of events, which further illustrates how a safety error chain often extends beyond a single

operator’s purview and onto other domains such as other airlines, air traffic control, airfield operations, and meteorology. Figure 2-19 shows the appearance of part of the flight deck instrument panel as part of the wreckage of the Concorde.

FIGURE 2-19 Part of the flight deck instrument panel from Air France Flight 4590. (*Source: French Bureau Enquêtes-Accidents*)

Findings and Causes

The following is a collection of noteworthy findings from the BEA investigation, showing within curly brackets whether the finding was also deemed causal in the accident sequence. Please pay close attention to which findings are considered causal and which findings are not considered causal in order to prepare to understand the contents presented in Chapter 6 of this book.

- A metallic strip from the thrust reverser cowl door of engine number 3 on a Continental Airlines DC-10 had been replaced in Tel Aviv in June 2000 during the aircraft’s “C” check, then again in Houston on July 9.
- The strip installed in Houston had neither been manufactured nor installed in accordance with the procedures as defined by the manufacturer.
- The metallic strip fell from the Continental Airlines DC-10 onto the runway during takeoff 5 minutes before the Concorde departure without detection by

the DC-10 crew, the airfield manager, air traffic control, or the Concorde crew.

- *{Causal}* A tire on the Concorde struck and came apart due to striking the metallic strip, expelling portions of the tire. Figure 2-20 shows how investigators analyzed the potential consequences of running over the metallic strip with a Concorde tire.

FIGURE 2-20 Analyzing the impact of the metal strip to the Air France Flight 4590 tire. (*Source: French Bureau Enquêtes-Accidents*)

- *{Causal}* Portions of the Concorde tire ruptured one of the Concorde fuel tanks. A part of the underside of tank 5 was found at the accident site and had a puncture 10 millimeters wide and 40 millimeters long.
- *{Causal}* The fuel leaking from the punctured tank caught fire from the electric arc in a landing gear bay or from contact with hot parts of an engine.
- The fuel that was leaking ignited; a flame and large quantities of smoke appeared behind and to the left of the aircraft. A large kerosene mark was found on the runway, immediately after the piece of the tank.
- Around 10 meters after the unburned kerosene mark, some soot marks on the runway and then some traces of burnt grass on the left edge of the runway were noted over a distance of 1,300 meters.

- *{Causal}* After the Concorde passed over the metallic strip, the rupture of fuel tank number 5, and the ignition of the leak, engines 1 and 2 suffered simultaneous surges leading to slight loss of thrust on engine 1 and a severe loss on engine 2.
- The surge on engine 1 was most likely caused by ingestion of hot gases or solid debris, probably pieces of tire, that on engine 2 resulting from ingestion of hot gases due to the fire.
- Because of the incomplete opening of the left main landing gear door or the absence of detection of opening of these doors, the crew was unable to retract the landing gear.
- Because of the lack of thrust and the impossibility of retracting the landing gear, the aircraft was in a flight configuration which made it impossible to climb or to gain speed.
- Many pieces of the aircraft found along the track indicate that severe damage to the aircraft's structure was caused in flight by the fire.
- Even with the engines operating normally, the significant damage caused to the aircraft's structure would have led to the loss of the aircraft.

RECOMMENDATIONS

In an effort to prevent similar accidents, the BEA published the following recommendations:

- Suspend the airworthiness of the Concorde until measures have been taken to guarantee a satisfactory level of safety associated with the destruction of tires.
- Air France should verify that emergency procedures in the section of Concorde utilization in the Operations Manual be in accordance with the Flight Manual.
- An audit should be conducted to analyze the operational and maintenance conditions of the Concorde within Air France.
- Aviation authorities should study the regulatory requirements and conform with requirements for aviation tires.
- Ensure a rapid implementation of a program for the management of debris on runways.
- The FAA should audit Continental Airlines maintenance practices both in the United States and in foreign locations.

INVESTIGATION

To conduct the accident investigation, multiple parties were involved. The team consisted of BAE Systems, Rolls Royce, FAA, NTSB, the German Federal Bureau of Aircraft Accident Investigation, Air France, and France's aviation accident investigation bureau (BEA). The head investigator established seven working groups to find and collect the information needed for the investigation.

The investigation was divided into the following areas: site and wreckage, aircraft/systems/engines, preparation and conduct of flight, flight recorders, aircraft performance, witness testimony, and examination of previous events. The results from these efforts allowed the BEA to publish a preliminary report of the accident. Further analysis was then conducted on the wreckage, the conduct of the flight and aircraft performance, previous events/certifications/regulations, and technical teardowns. A final report was then released detailing the findings, causes, and recommendations for the event. Figure 2-21 shows the field portion of the aircraft/systems/engines portion of the investigation, where personnel can be seen examining what is left of the upper nozzles of one of the engines.

FIGURE 2-21 Investigators assessing the upper nozzle of engine number 4 of Air France Flight 4590. (*Source: French Bureau Enquêtes-Accidents*)

It should be noted that the previously depicted findings and causes for this accident did not clearly distinguish between the root causes and the active causes of the accident. Such a distinction may not be evident in an accident investigation report unless the full report is read to include the background analyses and interviews that were performed. In the case of the Concorde accident, a careful examination of the proffered recommendations will reveal that they address several root causes of the tragedy.

When reading through the findings and causes of this accident, we can see the multicausality “Swiss Cheese” principle quite clearly. The multicausality principle states that accidents result from numerous factors combining to create an accident sequence. To begin, the metallic strip that fell off the Continental Airlines DC-10 had not been installed per the manufacturer’s specifications. It is probable that the improper installation led to the part detaching from the plane. This event combined with the airport management’s inability to detect that there was a foreign object on the runway.

The DC-10 pilots could not be expected to detect when a small part such as the metallic strip fell off their aircraft, and the Concorde pilots certainly could not see such a small part as they rolled down the runway with their focus on the other aspects of takeoff, such as monitoring airspeed and engine performance. The multicausality principle in this accident showcases the role of other personnel in the sequence of events, such as the Continental Airlines aviation maintenance technicians, the Paris airfield managers, and even Air France for not taking precautions to prevent what it turns out was an already noted hazard of having tire debris from the blown tires puncture fuel tanks.

One aspect that makes this tragic accident particularly interesting is that two aircraft were involved as part of two different events, separated by time, but then one event had a direct impact on the other when the dropped part of one aircraft caused damage on the second aircraft. Such a combination illustrates the complex nature of the accident. When such special complexity is introduced, the size of the investigation increases since there are more factors involved worthy of analysis. Investigators need to examine not only the safety breakdown of both aircraft individually, but also how safety degraded between the two aircraft as a coupled system. Such an intricate dance of variables helps us understand the previously stated concept that complex problems do not have simple solutions.

It is also worth noting the temptation to only determine the active causes of the accident without discerning the critical root causes. Investigators of the

Concorde accident correctly dug deeper into the causes to extricate the root issues that contributed to the accident. For example, let us consider the finding that the metal strip had been installed incorrectly on the DC-10. We could write the factor off as maintenance error, but doing so and going no further would not achieve our goal of permanently fixing problems to improve safety. In the Concorde case, investigators found out what had happened and correctly kept investigating in order to find out all the reasons why the accident happened by studying why the metal strip was installed incorrectly.

Was it a case of the maintenance team performing a shift change and not providing proper work continuity? Perhaps one or several aviation maintenance technicians were fatigued or dehydrated due to scheduling practices or lack of proper facilities for work? What if the guidance provided to aviation maintenance technicians was wanting? Was the training of such specialists insufficient? To figure out the answer to these possibilities investigators have to trace problems back to operations management and external support. Depending only on the active causes of accidents will leave the underlying issues unaddressed and, thus, accidents related to the unaddressed factors will continue to occur. We can't just look at the superficial level in which causes occur; we must always seek out the root causes.

Lastly, the example of the metal strip on the runway relates back to the *medium* component of the 5-M model. In this case, the environment for flight was jeopardized because of a hazard on the runway. The strip was an artificial portion of the environment that should not have been naturally present. Only once we are able to address each and every component of the 5-Factor model can we hope to detect the key components of a safety error chain.

CONCLUSION

This chapter has explored some of the fundamental concepts underpinning accident theory. Understanding the theory is aided by the use of models, some with highly creative names such as the "Swiss cheese," SHELL, and 5-Factor models. All models have one common element: the fact that accidents are caused by more than one factor, a core principle of accident theory called multicausality. Yet in spite of using such depictions to portray the complexity of accident theory, a popular but flawed idea is still held by the media and general public that most accidents or incidents can be traced to a single human failure somewhere, often mischaracterized simply as "pilot error."

The reality of the matter is that human failure is very much present, but should be viewed as extending far beyond the immediate and active acts of those

who are closest in time to an accident. An aviation maintenance technician who improperly replaced a hydraulic pump or an air traffic controller who erroneously cleared an aircraft to land on an occupied runway may only represent active causes of an accident, whereas accident theory tells us that such active causes have deep roots that must be investigated to prevent future incidents and accidents.

Machines are designed, built, and operated by humans. Thus, a failure of a machine is really a failure of one or more humans who designed the machine. Likewise, humans may not avoid or eliminate known environmental hazards, or they may create additional hazards. Thus, these could all be considered failures of humans rather than environmental failures. This interpretation, therefore, accounts for the wide discrepancy in the percentages of accidents attributed to human failure reported by different sources.

The visual conceptual models discussed in this chapter clearly show that many aviation hazards are brought about by problems at the interface between technology, human, and organizational factors. A combination of these elements can be found in the error chain, as accidents generally have many contributing factors. Such an idea of *multicausality* at different levels of an organization, as pioneered by James Reason, underpins accident theory and prompt all members of the safety value chain to be aware of his or her role in accident prevention. If investigators neglect one piece of the accident puzzle, that factor may show up as a cause of yet another accident.

It must be noted that in aviation, it is practically impossible to attain an environment devoid of threats to safety. Safety has been defined as the freedom from risk or danger, but whenever people are working with objects that move very fast under human control and have high potential energy, there will always be some sort of risk present.

As is obvious by the concepts in this chapter, the human element is critical to the safety value chain. Humans engender the idea for an aircraft or other piece of aviation equipment, then assemble components and the overall aircraft, and finally also train professionals and operate the equipment. There are many ways that humans can commit unsafe acts or underperform due to human limitations during any of those phases. Therefore, the next chapter will explore the challenges presented to commercial aviation safety by the human tendency to commit errors and to fail at tasks that demand high reliability. The next chapter will also delve into the changing nature of expertise in aviation and other human tendencies that can combine to create error or less than optimal performance. We will also look at the relationship between professionalism and safety and explore the intimate relationship between humans and automation on the modern flight

the intimate relationship between humans and automation on the modern flight deck.

KEY TERMS

“4 Ps” of Human Performance
5-Factor Model
Accidentology or Accident Theory
Active or Proximate or Apparent Cause
Causation
Cause
Complexity
Error Chain
Human Factors
Multicausality
Predictive Safety
Proactive Safety
Professionalism
Reactive Safety
Reason’s “Swiss Cheese” Model
Reasonable Person Concept
Root Cause Analysis
Root or Enabling or Latent Cause
SHELL Model
Unsafe Acts
Visual Conceptual Model

REVIEW QUESTIONS

1. Which area do you think safety analysts should focus on the most today: technical factors, human factors, or organizational factors?
2. How do the recommendations stemming from West Caribbean Airways Flight 708 illustrate the need for root cause analyses to prevent future accidents in commercial aviation?
3. Explain the difference between active causes and root causes.
4. Explain the difference between findings, causes, and recommendations.

5. Why do we use models, such as the SHELL and 5-Factor models, to learn accident theory?
6. Do you think it is possible to develop simple solutions to complex aviation problems?
7. What are some logical fallacies that directly relate to accident theory?
8. Do all problems stem back to one or more root causes, or is it possible that some causes are simply *active* and exist without roots?
9. Explain Reason's "Swiss Cheese" model of defensive layers to include the concept of latent and active failures.
10. Develop a fictional accident that is the result of two holes in the "Swiss Cheese" model.
11. Why is "Liveware" always in the center of the SHELL model?
12. Are there any other elements that you think should be accounted for in the 5-Factor model?
13. The medium or environment includes two parts, the natural environment and the artificial environment. Compare and contrast the two parts.
14. How does the role of luck impact commercial aviation safety? How is luck featured in accident models?
15. Write a short paragraph explaining how the case study of Air France Flight 4590 exhibits the major concepts of this chapter.
16. Produce a recommendation to prevent accidents based on the Air France Flight 4590 case study, then speculate as to reasons why such a recommendation may not have been part of the accident report.

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CHAPTER THREE

HUMANS AS THE CHALLENGE

Web References

LEARNING OBJECTIVES

After completing this chapter, you should be able to

- Understand philosophical elements of human error.
- Detail why we should not use only “pilot error” as a source of accidents.
- Discuss how human factors and human performance contribute to accidents.
- Explain situational awareness and how it can affect aviation professionals.
- List and explain the factors that affect human performance, giving examples of each.
- Describe what the investigation of human error entails.
- Describe what the management of human error entails.
- Describe the difficulties associated with ensuring that flight crew are both physiologically and psychologically healthy.

INTRODUCTION

Is commercial aviation special? Yes, but only in the same way that other high-consequence businesses are special. By that we mean that there are some professions where relatively small mistakes can have very large negative consequences. For example, an otherwise innocent distraction of a commercial airline flight crew right before landing, such as from a laser or bird, could cause the pilots to undershoot the landing and touch down just prior to the runway. Implications from this could include the death of hundreds of passengers and paralysis of operations at a major airport for hours. Professionals working in commercial aviation, like those who operate nuclear power plants, aircraft carriers, or high speed trains, cannot afford to make small mistakes because of the potential for huge negative consequences. When such mistakes make it through the defenses we have created, terrible disasters can occur. So in this sense, yes, commercial aviation is special.

As indicated, commercial aviation is considered a high-consequence environment because even small mistakes can be disastrous. Some refer to those types of businesses as being conducted by *high-reliability organizations*, *high-risk industries*, or *high-consequence operations*, where all terms are expressions

of the same sentiment.

When considering how small errors trigger large problems, it becomes clear why commercial aviation operations require very special safeguards to protect against the potentially terrible outcomes from minor mistakes. It also becomes evident why an entire chapter of this book is dedicated to the challenge of dealing with human fallibility. It is an ever-present condition that follows us as a shadow through life, rearing its ugly head all too often to remind us that as humans we are very error prone.

This chapter explores humans as a major challenge in commercial aviation. All the technical knowledge in the world does not guarantee a successful outcome to a complex, technical situation. Whenever people are part of the equation, we rely on procedures, communication skills, teamwork, experience, and extensive training to properly use any technical knowledge to produce an acceptable outcome. Sometimes it all goes wrong—terribly wrong.

PHILOSOPHY OF HUMAN ERROR

It was a curious sight to behold at the beach. A young osprey, which is a type of bird, hovered approximately 30 feet above and just offshore. Ospreys are among the supreme hunters of the avian world. Scanning the water below for fish, its head tracking back and forth, back and forth like a radar dish; the bird resembled nothing so much as a miniature jet fighter scanning the skies for the enemy. Suddenly its gaze locked on a target. Furling its wings, it swooped down toward a fish like a fighter pilot diving into combat. Usually an osprey's dive terminates in a stunningly graceful display of airmanship as the plunge is broken and the prey captured with a fierce piercing of talons. This time, however, the attack did not go as planned. As the descending bird neared the water, a sudden flutter of wings altered the flight path radically just prior to the point where the talons should have sunk into the prey.

Perhaps the abrupt maneuver was due to the osprey seeing a more desirable fish or a menacing shark; perhaps it was a reaction to a last-second change in the prey's position. Regardless of the reason, instead of ending with an elegant talon-grab, the modified approach resulted in a spectacular semi-controlled crash into the water. After impact, the stunned hunter paused momentarily to gather its senses, then slowly flapped its wings, struggled free of the water, and took flight while letting out some pained squawks of avian profanity, reflecting no doubt its confused mental state.

With a bit of anthropomorphic imagination we can hear the osprey flying

away and thinking, “Well, that approach was terrible! What happened? Everything was looking good and then suddenly, crash. Lucky I could fly away from it. I really need to stick to stabilized approaches or go around!” We doubt the osprey safety community convened an accident investigation board, submitted an anonymous *pilot error* report, or held a safety standdown; but it is likely that the osprey learned from the incident. If not, the future bodes ill for survival because the mortality rate of young raptors is very high, and only the fittest and best adapted survive.

Consider now the story of a human rather than that of the avian hunter. Near the beach where the osprey crashed into the sea there is a drawbridge—popular with fishermen—that spans the inland waterway. Above the bridge, an electrical line runs parallel from the mainland power generating station, across the waterway, and to the beachside barrier island. For most of this stretch, the power line is 40 feet or more above the lowlying bridge. Where the bridge rises toward its draw above the waterway channel, however, the distance between the bridge walkway and the power line diminishes to about 10–12 feet. This distance provides a significant inconvenience for fisherman casting lines from the rise of the draw into the waters of the channel. And, of course, fishermen prefer to fish from the draw rather from the lower bridge because the channel is where the big fish lie in wait.

As shown in Figure 3-1, the power line in the area of the bridge’s draw is covered with bobbers, hooks, lures, sinkers, bits, and pieces of line—the remains from countless miscasts. In one sense it is a small, yet notable, monument to human fallibility and to the repetitive nature of error. Imagine the next angler who challenges the power line. Prepping the gear to catch a trophy fish from atop the draw, the angler says to his fishing buddy, “Look at all those lures up there. I wish I could get up there and cut me some down for my tackle box.” Moments later, the angler casts his line and yells out, “Oh no, I just got caught up in the power line! I can’t believe it. What bad luck!” The angler’s problem with the power lines was not a matter of bad luck. He knew—or should have known—that a threat existed.

FIGURE 3-1 Fishing lines, weights, and lures caught in a power line. (*Source: Authors*)

The story of the frustrated angler reminds us that every time our personal performance does not meet our expectations, we are presented with an opportunity for improvement. Seizing such opportunities constitutes what has been called *embracing our blunders*. Similarly, when we avoid blunders by learning from the missteps of others who have preceded us, we are embracing the blunders of others. Some people simply dismiss missteps as examples of human fallibility. Others may take the cowardly position of covering up their actions or redirecting blame instead of learning from their embarrassing missteps. It takes courage to foster improvement by actively seeking out and embracing shortfalls. Nonetheless, we must not fail to do so.

In commercial aviation safety we must constantly strive to recognize and analyze our errors and those of others. In doing so, we prepare ourselves to recognize developing accident chains and the opportunity to intervene before they result in tragedy.

WHO IS THE ACE?

What does an aviation professional look like today? What does it take to add to the *safety value chain* that over the past quarter century has produced the lowest accident rates seen in commercial aviation history? Let us first focus on the flight crew for a moment, while realizing that similar changes have occurred for other professions within commercial aviation. Ponder the following question. How would you define an excellent pilot? Is it someone with a type-A personality, muscular physique, and a former high school football captain, who can pull on the yoke to recover from a steep dive while barking orders at his crew? There are still a few remaining pockets around the world where such an

image holds true. For the most part, however, the past few generations have witnessed a significant evolution in the desirable traits sought in pilots. We have witnessed a subtle, but persistent, transformation in the description of an expert pilot.

While pilot actions and decision making used to suffer from a lack of information, today pilots have to sift through a multitude of resources and information when they make decisions. The very nature of the profession has been redefined. Intuition and luck have given way to knowledge and procedural discipline. How pilots manage the information avalanche determines the outcome of a flight, and a result defines their worth as aviators. Today, the new vision of an excellent pilot is of someone who can coordinate the actions of numerous highly trained team players while mastering the technical intricacies of a complex system, knowing which resource to tap from an extensive collection, all with grace and a level head in a time-sensitive environment.

During the early days of aviation, airmail pilots had to create a mental model of what was happening based on miniscule amounts of data, many of which were unreliable. Some would use hand-scribbled descriptions of airfields and surrounding terrain from previous flights, determine wind direction by noticing the direction that cows were facing, or estimate how much fuel was remaining in the tanks by trying to remember what time it was when they departed on their flight.

The professionals on the flight decks of commercial aircraft today increasingly work in an all-glass, computer-enhanced cockpit. Often through the use of electronic tablets, they can summon weather observations and forecasts for numerous locations simultaneously, weight-and-balance calculations, notices about taxiway closures, navigation transmitter statuses, and computerized flight plans from highly competent dispatchers, reference updated procedural guidance, and use flight deck instruments to receive data-linked air traffic clearances and weather radar depictions.

All this information helps create a mental model of the operating context, but only if properly presented and interpreted. Can too much information be just as detrimental to the safety of the flight as insufficient information? The definition of an expert pilot today is not one who can make accurate decisions without proper information. Rather it is one who knows how to seek out the right type of accurate information and apply it at key moments, all while operating the aircraft at peak efficiency through automated flight control systems while fostering outstanding teamwork among the crew.

Figure 3-2 depicts the appearance and features of a modern flight deck. The

access to information is unrivaled and so is the need to know where to go and what to do with the information as a pilot. Similar technological advances have required other professions that impact the safety value chain, such as dispatcher and aviation maintenance technician, evolve in order to make decisions in an information-rich environment.

FIGURE 3-2 The modern flight deck. (*Source: Authors*)

Technology may be changing, but the need for so-called *soft skills* remains imperative. It is widely recognized that pilots must possess equal doses of technical expertise and polished human interaction skills. The increasing complexity of technology, airspace, regulations, and procedures mean that pilots must have complete knowledge of their realm. *Automation* produces gain in efficiency and *situational awareness*, but only if the pilots who use it are proficient in how it operates during both normal and emergency situations.

Additionally, pilots must possess the human interaction skills, including effective communication, leadership, and followership. Such soft skills sound intuitive but are actually very complex, requiring professionals to combine an open mind for learning new concepts with the commitment to putting crew communication and coordination into practice, as will be the focus of the next chapter in this book.

Some of the challenges faced by aviation professionals today remain the same as those a century ago, such as fatigue, dehydration, and schedule pressures. Yet there are new challenges that must also be addressed, such as *information overload*, interfacing with complex automation, and high density of air traffic. The next section provides an introduction to such factors.

HUMAN FACTORS

The people who operate and support the U.S. aviation system are crucial to its safety; the resourcefulness and skills of crewmembers, air traffic controllers, and aviation maintenance technicians help prevent countless accidents each day. However, despite the excellent safety record, many studies attribute human error as a significant factor in most commercial aviation accidents.

The leading human-factors theorists and modern researchers believe that between 70% and 80% of all aviation accidents are attributable to human error somewhere in the chain of causation. Modern aviation safety theory at present is heavily focused on trying to understand the human decision-making process. It aims to understand how humans react to operational situations and interact with new technology and improvements in aviation safety systems. The way in which human beings are managed affects their attitudes, which affects their performance of critical tasks. Their performance affects the efficiency and, therefore, the economic results and safety of the operation.

It is important to understand how people can be managed to yield the highest levels of error-free judgment and performance in critical situations, while at the same time providing them with a satisfactory work environment. A review of cockpit voice recordings from accidents clearly indicates that distractions must be minimized, and strict compliance with the *sterile cockpit rule* must be maintained during the critical phases of flight (taxi, takeoff, approach, and landing). The sterile cockpit rule, in its different forms, is a ban on nonpertinent conversation among members of a flight crew during critical phases of flight to minimize distraction.

While emphasis often focuses on the pilots, they are by no means the only ones who should be discussed in the sterile cockpit rule philosophy. The same holds for all human factors–related initiatives. Pilots are, however, the last link in the safety value chain and are usually in a position to identify and correct errors that could otherwise result in accidents and incidents. One problem is poor human decision making. Essentially, three reasons explain why people make poor decisions:

- They have incomplete information.
- They use inaccurate or irrelevant information.
- They process the information poorly.

Psychologists have traditionally explained the limited information processing

capabilities of humans with *Miller's law*. George Miller was a cognitive psychologist at Princeton University when in 1956 he published what would be known as his law. Miller's "Magic number" concept states that one can make 7 (plus or minus 2) absolute judgments, or differentiations, along a single dimension. For example, we can differentiate seven sound intensities and seven shades of the color red, plus or minus two in both examples. This idea has been applied to the number of mental objects an average human can hold in working memory. Such an ability is improved when a pilot uses both his visual and auditory channels because the information is processed differently in the brain.

Although the reality is much more complicated than that has been summarized here with regards to Miller's law, the sentiment still holds. Modern research has shown that accidents are more likely to occur during high workload, task saturation periods, and when there is an overload of one or more of the pilot's processing channels. To reduce the workload during critical task saturation situations, new pilots are taught a task-shedding strategy to focus on the most important task on the flight deck: flying the plane. As simply stated in Figure 3-3.

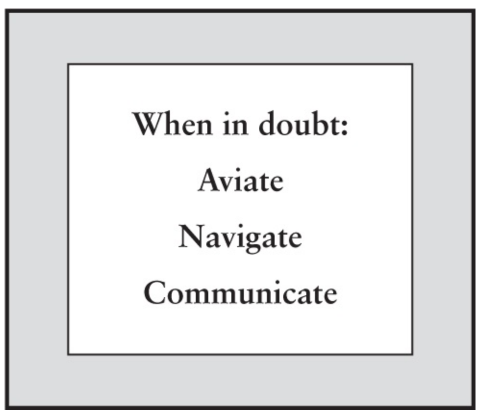

FIGURE 3-3 Aviator's priorities at all times when operating an aircraft. (*Source: FAA*)

In other words, in an emergency, fly the plane first, then if circumstances permit, navigate, and finally, if the other two tasks are in hand, communicate with air traffic control. Too many accidents have occurred when pilots prioritized navigation or communication instead of actually controlling the aircraft. There is a common expression in the flight instructing world that emphasizes this hierarchy of priorities: "don't drop the airplane to fly the microphone."

Post-accident investigations usually uncover the details of what happened. With mechanical failures, accident data analysis often leads logically to why the

accident occurred. Determining the precise reason for human errors is much more difficult. Without an understanding of human behavior factors in the operation of a system, preventive or corrective actions are impossible. Understanding *human factors* is especially important to systems where humans interact regularly with sophisticated machinery and in industries where human error–induced accidents can have catastrophic consequences. Human factors principles are increasingly folded into design standards in the design of aviation systems, such as the seating and display control interfaces on a flight deck. However, such principles are sometimes not treated as a technology in commercial aviation where technical decisions in aircraft designs, regulations, and operations are primarily based on “hard” sciences, such as aerodynamics, propulsion, and structures.

Human capabilities do not often lend themselves readily to consistent, precise measurements. Human factors research requires much more time and cooperation than most other aeronautics research. Data on *human performance* and reliability are regarded by many technical experts as “soft” and receive little attention in some aviation system designs, testing, and certification. Data used in designs are often after the fact.

Aviation human factors is a multidisciplinary science that attempts to optimize the interaction between people, machines, methods, and procedures that interface with one another within an environment in a defined system to achieve a set of systems goals. Aviation human factors encompass fields of study that include, but are not limited to, engineering, psychology, physiology, anthropometry, biomechanics, biology, and certain fields of medicine. Human factors science concentrates on studying the capabilities and limitations of the human in a system with the intent of using this knowledge to design systems that reduce the mismatch between what is required of the human and what the human is capable of doing. If this mismatch is minimized, errors that could lead to accidents will be minimized, and human performance will be maximized.

By looking at Figure 3-4 we are prompted to contemplate numerous human factors, such as the comfort of the seats on the flight deck, the mental preparedness of the pilots to fly, the visibility from the flight deck of the ramp area when looking through the windshield, the ability to find specific knobs on the panels by touch alone, the ease of interpreting the written information in front of the pilot in the right seat, the color-coding of annunciator lights shining in the display panel, the verbal and nonverbal communication occurring between both pilots, and dozens of other considerations.

FIGURE 3-4 The flight crew of an Airbus 319. (*Source: Wikimedia Commons*)

ERROR CHAINS

In the first-century AD, the Roman stoic philosopher Seneca is often attributed the Latin musing, "errare humanum est perseverare diabolicum," meaning that it is human to make mistakes but it is downright devilish not to do something about that tendency. Throughout the ages, philosophers and safety advocates have wrestled with the notion of human error and have proposed different means for preventing error from occurring and ways to perform damage control once an error is made.

Some of the human error initiatives have resulted in prerequisite knowledge, skills, abilities, and psychological standards that are used for selecting and training aviation professionals. Other ideas have been directed at employees who are already exercising their profession. *Crew Resource Management (CRM)* and

Threat and Error Management (TEM) are two of the most recent and widespread expressions for managing error in flight operations and both rely heavily on using the positive synergy of teamwork.

From a philosophical perspective, one of the greatest achievements in the aviation safety movement over the last century has been the recognition that accidents seldom occur due to a single cause. According to the theory of accident *multicausality*, every causal mechanism involves the joint action of a multitude of component causes. Recognition of multicausality by accident investigators has allowed error intervention methodologies to target a plethora of human breakdowns that typically lead to accidents.

As Chapter 2 pointed out, accident investigators dig up an *error chain* by "reverse engineering" the accident's causes, so to speak. Whenever something of relevance is uncovered, an investigator must probe deeper by asking, "Yes, but why did that occur?" By asking, "Why? Why? Why?" over and over, an investigator can usually uproot most of the causal tree instead of just seeing the obvious branches. Only then can all the shortcomings of training programs, coordinating agencies, and quality-control measures be addressed to prevent future problems.

An experienced investigator picks apart each of these causes and asks all the "whys" of each, until a comprehensive picture of the failures is seen and corrective actions can be recommended. Each error by itself will not bring down an aircraft, but the likelihood of an accident increases with each error "link" added to the chain.

IS "PILOT ERROR" A MYTH?

It is almost impossible to open a book on flight safety or CRM that does not promptly refer to the high percentage of accidents that are caused due to pilot error. Although the numbers vary depending on which source is quoted, experts and records typically refer to large percentages of aircraft accidents as being caused by pilot error.

In 1999 the Data Acquisition and Analysis Working Group of the Flight Safety Foundation analyzed 287 fatal approach-and-landing accidents involving jet and turboprop aircraft between 1980 and 1996. The study noticed that CRM breakdowns were present as circumstantial factors in nearly half of the accidents. The same study looked at 76 approach-and-landing accidents between 1984 and 1997 and found that CRM failure was the third most frequent causal factor (63%) and the second most frequent circumstantial factor (58%) (Khatwa & Helmreich, 1999).

In yet another example, in 2001 a group of researchers from the Department of Emergency Medicine at Johns Hopkins University School of Medicine analyzed 329 major airline crashes, 1,627 commuter/air taxi crashes, and 27,935 general aviation crashes for the years 1983 through 1996. They found that pilot error was a probable cause for 38% of the major airline crashes, 74% of the commuter air taxi crashes, and 85% of the general aviation crashes (Johns Hopkins, 2001).

Although some of the depicted statistics refer to *human* error, versus *pilot* error, make no mistake that the average public consumer of information completely interprets both terms to be synonymous when discussing it in the aviation context. Of course, experienced investigators are quick to point out that using the term *human* opens up the possibility of analyzing root errors that took place outside of the purview of the flight crew. Such root errors may have not been perceived by the accident flight crew, but helped induce the active errors of the flight crew that immediately preceded the accident.

Society often neglects to consider that humans have also had a hand in all the automation that surrounds us. It is incorrect to ask, “Is it a human problem or an automation design problem” since a human had to design the automation. Similarly, it is incorrect to ask, “Was it human error or mechanical failure” if the mechanical failure was due to an inspector failing to catch an existing fracture in a component. Both the pilot and inspector are human, and human error makes no distinction as to the profession being performed by a person.

There are times, however, when pilot error truly is a critical factor in an accident. When a series of errors takes place that leads to an accident, and all of those errors are created by the flight crew, then it is tempting to assign cause to them and not look at contributing factors such as training or procedures. This is especially the case when the flight crew was properly trained and procedures existed but mistakes were still made. Stunning statistics exist about the very high percentage of accidents attributable to pilot error. What is truly shocking about such statistics is that the statistics are shocking in the first place. Who came up with the notion that pilots should not make mistakes? Are pilots somehow supposed to be exempt from human nature?

Historically, accidents were often conveniently written off by deeming the cause to be “pilot error” and taking scant further action. The public was relieved to know that a single “bad apple” had created the problem, and after a period of shock and grieving, the aviation world would return to business as usual. In a sense, we treated the symptoms of a disease while permitting the underlying cause to grow unchecked.

Such a process may possibly have originated because many of the pilots

Such a process may possibly have originated because many of the pilots involved in accidents did not survive to defend their reputation, and some companies found it convenient to excuse any possible mismanagement leading to the accident by assigning cause exclusively to the dead pilots. Also, the science of accident investigation only recently developed to the point where root causes form part of the investigation process. Lastly, the general public is usually not educated in the complexities of aviation and seeks simple answers instead of complicated accident causes. One is reminded of the saying, "You want it bad? You'll get it bad!" Aircraft accidents are complex multicausal puzzles that demand time and attention to detail to solve. The first few days following an aircraft accident can be summarized as an amorphous and emotional mass of conflicting eyewitness reports, misdirected reporters' questions, a tendency to believe initial causal theories because they sound good, and the temptation to oversimplify what happened. To wade through all that chaos, accident investigators must exercise patience and focus on minutiae, yet strive to see the big picture.

Is calling "pilot error" a *myth* meant to remove individual accountability from pilots in terms of error management? Absolutely not; it is merely to point out that such characterization is a "cop out" or an excuse for not solving the real root cause problem. Over the past decades several high-profile accidents, such as the loss of the Challenger and Columbia space shuttles, called dramatic attention to the effects of organizational root errors. Some accident scientists fear that the increased emphasis on organizational errors as part of an accident sequence has detracted attention from the phenomena of pilot error. In reality, both root and active errors must continue to be addressed as part of a coordinated attack to reduce accident rates.

COGNITIVE ERROR

In the past, human factors' analyses of aviation accidents and incidents have relied on "loss of situational awareness (SA)" or similar generalized descriptions as a simplistic label and have propagated the use of such a catch-all term with great alacrity throughout accident reports. "Loss of SA" and "breakdown in SA" are commonly used umbrella terms that mask the multitude of cognitive breakdowns that caused the ultimate loss of SA. The use of "loss of SA" as a causal finding for an accident, although technically correct, proves insufficient for exposing where the breakdown in SA occurred. Therefore, aviation training specialists have been unable to develop effective measures for teaching how to prevent the erosion of SA past a certain superficial level.

Critics argue that investigators need "... access to the psychological life

Critics argue that investigators need, "… access to the psychological life beneath an error … more guidance beyond a cursory analysis … if one is to truly understand the genesis of human error" (Wiegmann & Shappell, 2003, p. 150). This section of the chapter examines some of the underlying cognitive processes that can lead to loss of SA.

"Cognition" is a term that refers to the mental processes generated in the brain and related to thinking. Cognition is defined by the *APA Dictionary of Psychology* as "all forms of knowing and awareness, such as perceiving, conceiving, remembering, reasoning, judging, imagining, and problem-solving" (Vandenbos, 2007, p. 187). As such, human cognition lies at the heart of every action taken prior to and during an aircraft's flight.

It proves daunting to consider that every aspect of a flight is controlled by a series of loosely networked, complex, error-prone supercomputers that are subject to a single point of failure—our brains! No user manual has ever been written to teach humans how to effectively use our brains. Our reaction to such a depiction may be shock and outrage, but that is the reality of the situation. We would not dare fly an aircraft or operate other complex equipment without first studying an operator's manual or receiving training, but that is essentially how we approach the use of our brains every day.

Accident chains can start forming way back during the design of an aircraft or system while still in the brain of an engineer due to errors in thinking or knowledge gaps. New errors or more errors can then be introduced in the brain of an assembly line worker who manufactures the aircraft and those mistakes, like the ones of an engineer, may not surface until later, during the life of the aircraft. The brains of numerous support personnel serve as external crewmembers for any given flight, and their errors directly impact the success of the flight. The brains of training department instructors and chief pilots create procedural guidance and teach pilots how to follow such guidance. The brains of government regulators provide oversight of operations. At the end of the long safety value chain are the brains of the pilots. We must recognize that causal errors in commercial aviation accidents almost always have some link to cognitive processes. Scholars of human factors are quick to point out that benefits reaped from automatic cognitive functions generally come at the expense of control over the processes. Automatic mental modeling and SA construction often rely on deep-seated biases that taint our actions and decisions without us even knowing about it but that occur in order to speed up our cognitive processes. We can conceive of cognitive biases as "thinking shortcuts" that generally work very well in that they help speed up our thought processes. In the case of verbal and nonverbal communication, our brain has been trained

since childhood to “fill in the gaps” when information is missing. Additional information on this important area can be found in the online supplement to this chapter.

SITUATIONAL AWARENESS (SA)

As previously mentioned, statistics show that the majority of aviation accidents are caused by human error. In fact, we would argue that if you expand the investigation of accidents to include contributing factors, as any good accident investigator would, then virtually all accidents are associated with human failure of some sort. Such failures often contribute to a loss of SA, which precedes the accident. The loss often acts as a catalyst for the accident to occur because such a loss deprives people from seeing the mounting errors that together usually lead to the accident, and therefore, they are unaware that any action is required to prevent the event.

Situational awareness has long been considered the bedrock of pilot action and decision making. The effectiveness of a flight operation and the decision processes that bolster such effectiveness are highly dependent on SA. In order to understand how SA is lost, we must first come to grips with what exactly is this mysterious entity known as SA. Because SA is an intangible concept and not necessarily intuitive to understand, many definitions have surfaced.

Perhaps the simplest definition of SA is “a mental model of one’s environment.” A more detailed definition of SA is “the ability to perceive factors that affect us and to understand how those factors impact us now and in the future.” But such a definition is incomplete since SA is more than perception. Others have defined SA in flight operations as “the realistic understanding of all factors which affect the safety and effectiveness of a flight”; except that such a definition implies that SA is realistic, whereas in reality we know there can be good SA and poor SA. A person also can have a continuously varying level of SA during a period of time. Still others have defined SA as “the understanding operators have of the system and its environment at any one time.” The problem with that definition is that SA is more than just understanding. As we can see, it is a complex topic that defies simple answers.

Interest in SA research increased significantly in the 1980s and accelerated through the 1990s. The surge in research was due to, in great measure, the increased use of automation and technology and the new type of mistakes that such innovations engendered. A significant moment occurred in 1995 when what would later be termed the Situation Awareness Error Taxonomy was created by a human factors researcher, Dr. Mica Endsley. She researched SA exhaustively

and realized that SA is developed, sustained, and destroyed along three distinct levels:

- Level 1 SA: ***perceiving*** *critical factors in the environment*
- Level 2 SA: ***understanding*** *what those factors mean*, particularly when integrated together with your goals
- Level 3 SA: ***projection—****understanding what will happen with the system in the near future*

So, in a nutshell, we can think of the three levels of SA as *perception, understanding, and projection***.** As such, the best definition of SA for this book is, “The perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future” (Endsley, 1995, p. 36).

The three levels form a hierarchy of SA where people must attain a lower level prior to moving onto higher levels of SA in order to retain good SA. In other words, the accuracy of SA at higher levels is intimately linked to the accuracy of SA at the lower levels. For example, a flight attendant directing passengers through an emergency evacuation on a taxiway who does not perceive the presence of fire outside of an emergency exit (poor Level 1 SA) cannot be expected to understand the risk of opening the exit (poor Level 2 SA), and therefore may inappropriately proceed to open the exit and direct passengers to exit into the fire (poor Level 3 SA). This would be considered poor overall SA, leading to death or injury of passengers.

By contrast to the previous example, the same flight attendant who correctly perceives the presence of fire outside of an emergency exit (good Level 1 SA) will be more likely to then understand the risk of opening the exit (good Level 2 SA), more likely to direct passengers to an alternate exit away from the fire (good Level 3 SA), and therefore be considered to have good overall SA, leading to a safe evacuation.

Based on the previous explanation, we can see that SA can be challenging to build and easy to lose. Imagine an aviation maintenance technician who is taking over the task of replacing a leaky oil pump from a colleague during a shift change. The handoff has to be carefully performed in order for the incoming technician to correctly perceive what tasks have already been accomplished (Level 1 SA), to then understand how the completed tasks fit into the overall process for replacing the pump (Level 2 SA), and lastly determine how she will proceed to complete the task (Level 3 SA). An error in the first level makes it

hard to correctly establish Level 2 SA. Or, the technician may correctly build Level 1 and incorrectly build Level 2 SA, making it difficult to determine the proper remaining actions (Level 3 SA). Even if the first two SA levels are correctly built, the technician may incorrectly determine the remaining actions and therefore end up with poor SA and an improperly replaced oil pump.

Why would it be difficult to establish SA at each level? Human factors scientists have stressed the need to investigate the psychological roots of each level of SA versus simply stating superficial descriptions of how poor SA contributed to an event. For too many years, and still in too many reports today, investigators simply explain the causes of an event as "loss of SA" without probing deeper. To say that an accident happened due to loss of SA is not very helpful. Why? It is not helpful because it does not allow us to prevent future accidents. After a bad event, we cannot simply tell aviation professionals, "don't lose SA in the future." That would be like demanding of a pilot, "don't crash again." That is not very helpful! Hence the reader has been exposed to the previous discussion in this chapter about the roots of *cognitive error*. Such errors and biases can work against creating SA at each level of the hierarchy.

Thinking about these errors can help us explain how SA breaks down. Continuing with our previous example of the technician replacing the oil pump, insufficient knowledge as to how to use a maintenance manual may lead to the technicians not knowing to consult a checklist and then not perceive a key checklist item in the oil pump change procedure (Level 1 SA). Or, perhaps an instructor in a training course improperly taught the incoming technician that several clamps were acceptable for connecting the pump fittings to the engine gearbox, whereas only one special type of clamp can be used for the oil scavenge line (Level 2 SA). Or, perhaps a false expectancy that a more seasoned colleague was going to check the work caused complacency leading to a rushed job to complete the replacement and get the aircraft back in service (Level 3 SA).

It thus proves necessary to study the underlying factors that make loss of situation awareness so prevalent and so detrimental to flight safety. One key factor that can both build and destroy SA, as previously mentioned, is expectancies. In the context of human psychology, an expectancy is an attitude or mental model that guides operators to relevant situation cues, thus determining how a person approaches a situation in order to increase the efficiency of his or her situation assessment (Strauch, 2004).

A false cognitive expectancy is the unreasonable anticipation of an event or condition that does not occur as envisioned. The determination of reason is a subjective assessment by the researcher based on experience and training. The

incorrect anticipatory mindset may be the result of conscious or unconscious cognitive processes (Cortés, 2011).

The reason why expectancies function as a crucial aspect of cognition is quite clearly to increase the efficiency of actions. Expectations about information can impact the speed and accuracy of the perception of information. Continued experience in an environment helps people to develop expectations about future events that predispose them to perceive the information accordingly. In fact, the constant fusion of cognitive expectancies to actual perceived situations in order to build SA, at the risk of suffering expectancy violations, has been shown as one of the most critical processes responsible for situation awareness creation and diminution. In other words, incorrect expectancies, together with a very long list of other mental biases, can both help create and destroy SA (Cortés, 2011).

There are numerous other factors that affect SA, such as poor communication. Bad communication can occur when a controller would like for a pilot to perform a certain action while the pilot does not know what the controller is asking of them. It also may occur between a captain and first officer, resulting in confusion among them that causes a loss of tracking of what the airplane is doing. Other important factors impacting SA are fatigue or stress. If an air traffic controller is fatigued or stressed, he would be less likely to perform a visual sweep of a runway ahead of an early morning takeoff and may not pay as close of attention to the situation as he should.

Let us look at a flight deck example of the same concept of how workload impacts SA. Imagine a pilot who leaves the flight deck to use the lavatory during cruise flight but shortly before commencing the descent for landing. The longer the pilot is gone from the flight deck, the less sensory inputs are received with information and workload requirements for the flight, and therefore the lower the pilot’s SA becomes. On the other side, once the pilot comes back from a lavatory break prior to descent for landing and notices that her colleague has already started the descent, the returning pilot may end up playing catch-up due to all the changes that have happened since she left the flight deck.

In addition to strapping back into the seat, adjusting the seat position, and donning a headset, the returning pilot will have to work hard to quickly assess the situation to build SA. She may find herself having to rush to get through checklists, change frequencies, call the company to announce their imminent arrival time estimate, and quickly glancing at the instruments to determine what exactly the aircraft is doing.

As a result, in spite of her best efforts to catch up with all the changes since she left the flight deck, the large amount of catch-up workload may result in the

returning pilot not noticing as the other pilot improperly sets a vertical speed mode instead of an airspeed mode in the flight guidance panel, resulting in the crew busting a speed limit at a certain waypoint during the descent, all which could result in a violation being issued by ATC. However, if the returning pilot has sufficient time to catch up with what is happening before her colleague starts making the erroneous mode input into the flight guidance panel, her SA may be sufficiently high that she catches the error and saves the day. This scenario illustrates how there is a *goldilocks zone*, so to speak, that is described as the optimal amount of work where there is not too little and not too much workload.

In conclusion, there are many actions that need to happen to have and keep good SA. Underlying factors can cause a loss of SA, and such a loss is often associated with negative outcomes, such as accidents. Researchers continue studying the ways in which SA breaks down and how aviation professionals can maximize the accuracy with which they build each of the three levels of SA. Professionals in commercial aviation must take full advantage of all the available sources around them, which include other team members, air traffic controllers, dispatchers, and flight attendants, in order to stay in the loop as to developments and thus keep their SA high, while postponing noncritical tasks or delegating tasks in order to prevent workload from getting too demanding.

HUMAN PERFORMANCE

When we think of performance, it is tempting to consider a race car and how we assess its performance by asking how fast it can negotiate a turn while not losing its grip on pavement, or by learning how long it takes to accelerate from zero to 60 miles per hour. What about us? Human performance can be defined as the manner, speed, and accuracy with which individuals accomplish tasks. It is a measure of human activity that expresses how well a human has carried out an assigned, well-defined task, or a portion of a task (task element).

Human performance is a function of *speed* and *accuracy*. Here we focus mostly on the accuracy component of human performance. If a task is not performed “accurately” in accordance with its requirements, an error has occurred. Accidents are generally caused by situations in which a person’s capabilities are inadequate or are overwhelmed in an adverse situation. Humans are subject to such a wide range of varying situations and circumstances that not all can be easily foreseen. Careful attention should therefore be given to all the factors that may have influenced the person involved. In other words, consideration must be given not only to the human error (failure to perform as

required) but also to why the error occurred.

Variables that affect human performance can be grouped into seven categories: physical factors, physiological factors, psychological factors, psychosocial factors, hardware factors, task factors, and environmental factors. These factors are now briefly reviewed.

1. *Physical factors* include body dimensions and size (anthropometric measurements), age, strength, aerobic capacity, motor skills, and body senses such as visual, auditory, olfactory, and vestibular.

2. *Physiological factors* include general health, mental blood flow and oxygenation, and medical conditions such as low blood sugar, irregular heart rates, incapacitation, illusions, and history of injury, disability, or disease. Also included in this category are human conditions brought on by lifestyle such as the use of drugs, alcohol, or medication; nutrition; exercise; sports; leisure activities; hobbies; physical stress; and fatigue.

3. *Psychological factors* include mental and emotional states, mental capacity to process information, and personality types (introverts and extroverts). Some human *personality traits* include the following:

- *Motivation* is a desire of an individual to complete the task at hand. Motivation affects one’s ability to focus all the necessary faculties to carry out the task.
- *Memory* allows us to benefit from experience. It is the mental faculty that allows us to prepare and act upon plans. Memory can be improved through the processes of association, visualization, rehearsal, priming, mnemonics, heuristics, and chaining. Memory management organizes remembering skills in a structured procedure while considering time and criticality. It is a step-by-step process to increase the accuracy and completeness of remembering.
- *Complacency* can lead to a reduced awareness of danger. The high degree of automation and reliability present in today’s aircraft and the routines involved in their operation are all factors that may cause complacency.
- *Attention* (or its deficit) determines what part of the world exists for you at the moment. Conscious control of attention is needed to balance the environment’s pull on attention. An intrapersonal accident prevention approach would describe the hazardous states of attention as distraction, preoccupation, absorption, and attention mismanagement—the inability to cope with tasks requiring flexible attention and focused tracking and steering. The inability to concentrate can lead to lack of (situational) *awareness*, which

has been identified as a contributing factor in many accidents and incidents.

- *Attitude* strongly influences the functioning of attention and memory. Attitudes are built from thought patterns. An intrapersonal approach to the attitudes of team members attempts to identify the desirable ranges between such hazardous thought patterns as macho–wimp, impulsive–indecisive, invulnerable–paranoid, resigned–compulsive, and antiauthority–brainwashed.
- *Perceptions* can be faulty. What we perceive is not always what we see or hear. Initial perceptions and perceptions based solely on intended actions are especially susceptible to error. An intrapersonal approach prescribes ways to make self-checking more efficient and reliable.
- *Self-discipline* is an important element of organized activities. Lack of self-discipline encourages negligence and poor performance.
- *Risk taking* is considered by some to be a fundamental trait of human behavior. It is present in all of us to varying extents since an element of risk is present in most normal daily activities. Risk will be present as long as aircraft fly and penalties for failure are high. Accordingly, the taking of risks needs to be carefully weighed against the perceived benefits.
- *Judgment and decision making* are unique capabilities of humans. They enable us to evaluate data from a number of sources in the light of education or past experience and to come to a conclusion. Good judgment is vital for safe aircraft operations. Before a person can respond to a stimulus, he or she must make a judgment. Usually good judgment and sound decision making are the results of training, experience, and correct perceptions. Judgment, however, may be seriously affected by psychological pressures (or stress) or by other human traits, such as personality, emotion, ego, and temperament. Good judgment is vitally important to making correct decisions.
  - *Aeronautical decision making (ADM):* The FAA describes ADM as a systematic approach to the mental process used by aircraft pilots to consistently determine the best course of action in response to a given set of circumstances (FAA Advisory Circular 60-22). The FAA Pilot's Handbook of Aeronautical Knowledge recommends the *DECIDE model* to provide the pilot with a logical way of making decisions. The DECIDE acronym means to Detect, Estimate, Choose a course of action, Identify solutions, Do the necessary actions, and Evaluate the effects of the actions (Figure 3-5).

The DECIDE Model of Aeronautical Decision Making

1.	**Detect.**	The decision maker detects the fact that change has occurred.
2.	**Estimate.**	The decision maker estimates the need to counter or react to the change.
3.	**Choose.**	The decision maker chooses a desirable outcome (in terms of success) for the flight.
4.	**Identify.**	The decision maker identifies actions which could successfully control the change.
5.	**Do.**	The decision maker takes the necessary action.
6.	**Evaluate.**	The decision maker evaluates the effect(s) of his/her action countering the change.

FIGURE 3-5 The DECIDE model has been recognized worldwide as an effective continuous loop decision-making process. (*Source: www.faa.gov*)

4. *Psychosocial factors* include mental and emotional states due to death in the family or personal finances, mood swings, and stresses due to relations with family, friends, coworkers, and the work environment. Some of the factors that cause stress are inadequate rest, too much cognitive activity, noise, vibration and glare in the cockpit, anxiety over weather and traffic conditions, anger, frustration, and other emotions. Stress causes fatigue and degrades performance and decision making, and the overall effect of multiple stresses is cumulative. Interactions with coworkers are influenced by two important variables, namely, peer pressure and ego.

- *Peer pressure* can build to dangerous levels in competitive environments with high standards, such as aviation, in which a person's self-image is based on a high standard of performance relative to his or her peers. Such pressure can be beneficial in someone with the necessary competence and self-discipline, but it may be dangerous in a person with inferior skill, knowledge, or judgment. For example, a young, inexperienced pilot may feel the need to prove himself or herself and may, therefore, attempt tasks beyond his or her capability. Humans have many conflicting "needs," and the need to prove oneself is not limited to the young or inexperienced. Some persons, because of training or background, have a fear that others may consider them lacking in courage or ability. For such persons, the safe course of action may be perceived as involving an unacceptable "loss of face."
- *Ego* relates to a person's sense of individuality or self-esteem. In moderate doses, it has a positive effect on motivation and performance. A strong ego is usually associated with a domineering personality. For pilots in command, this trait may produce good leadership qualities in emergency situations but it

may also result in poor crew or resource management. The domineering personality may discourage advice from others or may disregard established procedures, previous training, or good airmanship. Piloting an aircraft is one situation in which an overriding ego or sense of pride is hazardous. Although usually not specifically identified as such in accident reports, these traits may often be hidden behind such statements as “descended below minima,” “failed to divert to an alternate,” “attempted operation beyond experience/ability level,” “continued flight into known adverse weather,” and so forth.

5. *Hardware factors* include the design of equipment, displays, controls, software, and the interface with humans in the system.

6. *Task factors* include the nature of the task being performed (vigilance and inspection tasks versus assembly operations), workload (work intensity, multitasking, and/or time constraints), and level of training.

7. *Environmental factors* include noise, temperature, humidity, partial pressure of oxygen, vibration, and motion/acceleration. It is important to note that the factors discussed above can act alone or in combination with two or more other factors to further degrade human performance in the occupational setting. These factors can produce synergistic effects on human performance. Some examples include an air traffic controller monitoring air traffic during extremely low air traffic volume while on allergy medication or a quality control inspector monitoring low-defect-rate products while on cold medication.

FITNESS FOR DUTY

Human performance is so important that the FAA has crafted a regulation dealing solely with the topic of *fitness for duty*. For many people, if they wake up not feeling well one morning, there is still a good chance they could survive the work day without putting anyone in danger. However, for aviation professionals, even the smallest disruption of balance in one’s body could severely compromise the safety of hundreds of people. Recent accidents have highlighted the need for future awareness campaigns and areas of research to improve fitness for duty.

The FAA explains fitness for duty in FAR 117.5 as being “physiologically and mentally prepared and capable of performing assigned duties at the highest degree of safety.” Unfortunately, there are gray lines in the meaning of the FAA definition as it is hard to standardize and quantify what physiological and mental fitness is for each professional.

Although the presence of stress in one's life has clear effects on performance, and alcohol can obviously severely impact performance, the *fatigue* element is less obvious and requires elaboration. Although it can be hard to pinpoint, fatigue is classified by the following:

1. Weariness from mental or bodily exertion
2. Decreased capacity or complete inability of an organism, an organ, or a part to function normally because of excessive stimulation or prolonged exertion

Fatigue can decrease short-term memory capacity, impairs neurobehavioral performance, leads to more errors of commission and omission, and increases attentional failures. A study of medical residents looked at the impact of fatigue and found that the risk of making a fatigue-related mistake that harmed a patient soared by an incredible 700% when medical residents reported working five marathon shifts in a single month (Hallinan, 2009). Think about how these same findings could cause breakdowns in safety for aviation professionals during long shifts. Some studies have shown sleep deprivation in pilots causing performance reductions equivalent to having a blood-alcohol level of 0.08% (Paul & Miller, 2007). In other words, being fatigued can deteriorate our performance as much as if we were drunk.

There are three types of fatigue: transient, cumulative, and circadian. Transient fatigue is brought on by sleep deprivation or extended hours awake. The second type, cumulative fatigue, is repeated mild sleep restriction or tiredness due to being awake for extended hours across a series of days. Last, circadian fatigue, is the reduced performance during nighttime hours, particularly between 2 am and 6 am for those who are used to being awake during daytime and asleep at night. Contributing factors to all types of fatigue include personal sleep needs, sleeping opportunities, physical conditioning, diet, age, alcohol, stress, smoking, sleep disorders, mental distress, sleep apnea, and even heart disease.

It is imperative to recognize the symptoms of fatigue because it is associated with accidents, reduced safety margins, and reduced operational efficiencies. In1993 the NTBS started including fatigue as a probable cause of some accidents, starting with the report on the uncontrolled collision with terrain by an American International Airways Flight 808, a Douglas DC-8 carrying cargo to Guantanamo Bay, Cuba.

Fatigue is a significant problem in aviation because of long shifts, circadian disruptions, and the sometimes unpredictable work hours. Attempts to regulate rest are limited by conditions that are still not adequately addressed, such as the

following:

1. Reporting for duty while being fatigued because stress from family or personal sources does not allow adequate sleep.
2. Commuting from home to the location where a trip will commence may require significant time awake and induce stress prior to actually commencing professional duties.
3. A crewmember may be provided an adequate rest period prior to a flight but may be unable to obtain quality rest due to ambient noise, such as when there is a party or a loud television in an adjoining hotel room, construction noise, or if the crewmember misuses allotted rest time for personal activities that are not conducive to rest, such as sightseeing or working a second job.
4. Traveling between time zones and not being able to be on a consistent sleep schedule.

Taking the above reasons into consideration, it is fortunate that there have not been more aviation accidents and incidents as a result of fatigue, particularly when contemplating that fatigue does pose a threat not only to pilots but also to air traffic controllers, aviation maintenance technicians, and everyone who can affect the safety value chain in commercial aviation.

The professional life of many people in aviation can best be described as shift work, which is a schedule that falls outside the traditional 9 am to 5 pm work day and which can include evening, night, morning, or rotating periods. Negative side effects of shift work include acute/chronic fatigue, sleep disturbance, disruption of circadian rhythm, impaired performance, cardiovascular problems, and family/social disruption. When operating while fatigued, controllers may commit an error, such as providing less than required separation between two or more aircraft and assigning closed runways to aircraft. Potential errors in maintenance may include incorrect assembly of parts, not properly installing equipment, and overlooking items that need attention.

To combat fatigue in the future, airlines have developed Fatigue Risk Management Plans (FRMPs). In 2010, the President of the United States signed Public Law 111-216, the Airline Safety and Federal Aviation Administration Extension Act of 2010, which focuses on improving aviation safety. Section 212(b) of the Act requires each air carrier conducting operations under Title 14 of the Code of Federal Regulations part 121 to develop, implement, and maintain an FRMP. Such plans consist of an air carrier's management strategy, including

policies and procedures that reduce the risks of flight crewmember fatigue and improve flight crewmember alertness. Further information on FRMP is contained in FAA Advisory Circular 120-103A, entitled “Fatigue Risk Management Systems for Aviation Safety.”

These guidelines provide a source of reference for managers directly responsible for mitigating fatigue, detailed step-by-step guidelines on how to build, implement, and maintain an FRMP, and describe the elements of an FRMP that comply with industry good practice. A typical FRMP structure consists of nine elements, all of which the carriers must address in their own plan:

1. Senior Level Management Commitment to Reducing Fatigue and Improving Flight Crew Member Alertness
2. Scope and Fatigue Management Policies and Procedures
3. Current Flight Time and Duty Period Limitations
4. Rest Scheme Consistent with Limitations
5. Fatigue Reporting Policy
6. Education and Awareness Training Program
7. Fatigue Incident Reporting Process
8. System for Monitoring Flight Crew Fatigue
9. FRMP Evaluation Program

By using this system, fatigue becomes a part of the safety management system in the same way other aspects of health, environment, productivity, and safety are managed. Additionally, the FAA has a few recommendations to mitigate fatigue, which are as follows:

1. Shift rotation time should be no less than 10 hours.
2. Utilize modeling and scheduling tools to assist in mitigating fatigue-promoting schedules.
3. Educate schedulers and workforce about issues regarding shiftwork and fatigue.
4. Promote application of personal and operational counter-fatigue strategies.

COMMUNICATION ISSUES

The term *communication* usually includes all facets of information transfer. It is

an essential part of teamwork, and language clarity is central to the communication process. Different types of communication, and verbal communication in particular, remain one of the weakest links in the modern aviation system. More than 70% of the reports to the Aviation Safety Reporting System involve some type of oral communication problem related to the operation of an aircraft.

Technologies, such as airport surface lights or data link communication, have been available for years to circumvent some of the problems inherent in ATC associated with verbal information transfer. Sometimes, however, solutions bring unintended negative consequences. For example, one potential problem with ATC data link communication is the loss of the “party line” effect (hearing the instructions to other pilots), which removes an important source of information for building pilot SA about the ATC environment. That being said, the so-called party line is also a source of errors for pilots who act on instructions provided to other aircraft or who misunderstand instructions that differ from what they anticipated by listening to the party line. Switching ATC communication from hearing to visual, as is the case with reading data link communiqués, also can increase pilot workload under some conditions. Further human factors studies are necessary to define the optimum uses of visual and voice communications.

Miscommunication between aircrews and air traffic controllers has been long recognized as a leading type of human error. It has also been an area rich in potential for interventions. Examples are the restricted or contrived lexicon (e.g., the phrase *say again* hails from military communications, where it was mandated to avoid confusing the words *repeat* and *retreat*); the phonetic alphabet (“alpha,” “bravo,” etc.); and stylized pronunciations (e.g., “niner” to prevent confusion of the spoken words *nine* and *five*).

Adequate communication requires that the recipient receive, understand, and can act on the information gained. For example, radio communication is one of the few areas of aviation in which complete redundancy is not incorporated. Consequently, particular care is required to ensure that the recipient receives and fully understands a radio communication. There is more to communication than the use of clear, simple, and concise language. For instance, intelligent compliance with directions and instructions requires knowledge of why these are necessary in the first place.

Trust and confidence are essential ingredients of good communication. For instance, experience has shown that the discovery of hazards through incident or hazard reporting is only effective if the person communicating the information is confident that no retribution will follow her or his reporting of a mistake.

The horrific ground collision between two Boeing 747 aircraft in Tenerife in 1977 resulted in the greatest loss of life in an aviation accident and featured a key communication error as part of the accident sequence. Today, controllers restrict the word *cleared* to two circumstances—*cleared to take off* and *cleared to land*—although other uses of the word are not prohibited. In the past, a pilot might have been cleared to start engines, cleared to push back, or cleared to cross a runway. The recommendation would have the controller say, “Cross runway 27,” and “Pushback approved,” reserving the word *cleared* for its most flight-critical use.

The need for linguistic intervention never ends, as trouble can appear in unlikely places. For example, pilots reading back altimeter settings often abbreviate by omitting the first digit from the number of inches of barometric pressure. For example, 29.97 (inches of mercury) is read back “niner niner seven.” Since barometric settings are given in millibars in many parts of the world, varying above and below the sea level pressure standard value of 1013, the readback “niner niner seven” might be interpreted reasonably but inaccurately as 997 millibars. The obvious corrective-action strategy would be to require full readback of all four digits.

A long-range intervention and contribution to safety would be to accept the more common (in aviation) English system of measurement, eliminating meters, kilometers, and millibars once and for all. Whether English or metric forms should both be used in aviation, of course, is arguable and raises sensitive cultural issues. At this time, the English system clearly prevails, since English is the ICAO-mandated international language of aviation, as stressed in a decree by ICAO regarding language proficiency on January 1, 2008.

HUMANS AND AUTOMATION

It is exciting when we get a new cell phone, isn’t it? Sure, it requires somewhat of a learning curve to master the new features, but once we determine how to use the new capabilities we feel so much more powerful with our new technology. That learning curve, however, can mean that you inadvertently delete your song list. That is a very minor mistake that is recoverable.

Wrestling with the automated features on a rental car makes the situation more serious, often requiring renters to sit in the parking lot of the rental car agency after receiving the car, with the engine running, while the driver figures out just how to figure out the fancy gadgetry. Or worse, the driver may try to figure out how to operate the technology in mid drive, creating distraction that

could lead to an accident.

Now imagine strapping into your brand new Airbus 350 and undertaking the same learning curve with the flight deck automation. A simple mistake is no longer a laughing matter. After all, you would be in a high consequence environment where a small error may not delete a song list, but result in the aircraft running off a taxiway or flying into terrain killing hundreds of passengers. It is not that funny anymore, is it?

On a much more serious note, the confusion caused by automation has surfaced time and time again in accidents. In 1992 an Airbus 320 operating as Air Inter Flight 148 crashed into terrain near Strasbourg, France, when pilots misunderstood the descent mode that was selected in the autoflight system. Two years later, an Airbus 300 operating as China Airlines 140 stalled on approach to Nagoya, Japan, when the automation confused the pilots and an unintentional go-around was initiated during approach to landing. More recently in 2013, a Boeing 777 operating as Asiana Flight 214 crashed on approach to San Francisco, partly because the crew did not understand how the aircraft's automation would behave in certain flight modes. According to Michael Feary, a research psychologist for NASA, part of the problem was that the information provided in the flight computer displays was written in "engineer-speak" versus "pilot-speak."

How automation combines with human error is a fascinating subject. You could write an entire book on the topic. In fact, many very good books have already been written. As a minimum, we should become familiar with three terms: *automation surprise*, *mode confusion*, and *GIGO* (*garbage in, garbage out*).

Automation surprise is when a person has a mental model of the expected performance of technology and then encounters something different. In some cases, we anticipate a response to the last selected mode but do not notice that the automation has reverted to a sub-mode, and thus, behaves differently than expected. Designers strive to make automation intuitive; however, operators may encounter functioning that they have not been taught and which is not announced by the automation control heads or associated displays. A study that surveyed 1,268 pilots revealed that 61% of them still were surprised by the flight deck automation from time to time (BASI, 1999).

For an example of automation surprise from everyday life, imagine that your laptop has a factory preset to check for updates every week and to restart if there are any. While writing a critical document that is due within the hour, a dialogue pops up detailing that the computer is going to start the scan and restart. You were away for a moment getting coffee and return to find the laptop rebooting.

were away for a moment getting coffee and return to find the laptop rebooting, much to your surprise. If you are lucky you did not lose much content on the document.

Within automation surprise, one specific aspect is *mode confusion*, which describes how selecting a certain mode for automation operation may actually result in a different mode being engaged, resulting in a very confusing situation. Mode confusion happens when we do not completely grasp the inner workings of automation or if we fail to monitor the automation as it operates, much as we would monitor a colleague to stay in the loop as to what is happening. One such situation is called an indirect mode change, when the automation changes mode without an explicit command by the operator, which is a byproduct of reaping the benefits of having automation perform what was previously manual functions. This happens more frequently than one would expect. A research study of 1,268 pilots revealed that 73% of them reported having inadvertently selected a wrong automation mode (BASI, 1999). Another study found that most mode confusion events occurred during unusual uses of the automation, such as during aborted takeoffs or disengagement of automatic modes during approach to landing (Sarter & Woods, 1995).

In 1995 the Federal Aviation Administration Aircraft Certification Directorate conducted a study about how modern glass cockpit automation correlates to aviation accidents stemming from automation confusion. The study demonstrated concern about pilot understanding, use, and modal awareness of automation, suggesting that when a pilot is not sufficiently engaged, awareness decreases. Another potential hazard that can result from mode confusion is altitude deviation. Using the ASRS database, NASA looked at 500 reports and found this to be the most reported automation problem. To correct this problem, the researchers recommend better and redundant feedback loops to detect anomalies, as well as new system designs altogether.

When mode confusion occurs, it can have significant consequences. How often are errors committed, though, and of what type? A University of Texas research team conducted Line Operations Safety Audits on 184 crews across three airlines between 1997 and 1998. They found that 68% of crews committed at least one error, the most frequent error being associated with automation. Sixty-five percent of these automation errors were a failure to verify settings. Incorrect switch or mode selection accounted for 21%. To understand the types of mode confusion that occurs, a NASA study used 30 flights aboard Boeing 757/767 aircraft to help categorize the types. The researchers divided mode confusion into two areas. The first was misidentification of an automation behavior when the actual behavior was different from what was expected. The second was when a pilot acted on the assumption that the machine was in one

second was when a pilot acted on the assumption that the machine was in one mode, when it was actually in another.

An example of mode confusion previously mentioned, Asiana 214, occurred in part because the flight officer controlling the Boeing 777 was in manual control of the aircraft yoke but mistakenly believed that the auto-throttle mode he had selected would control the airspeed. When the pilot noticed the dangerously slow speed on approach and realized that he was confused about the auto-throttle mode, he intervened by trying to take manual control of the aircraft instead of using the automation, but it was too late to prevent the accident.

Another source of human error when using automation is GIGO, an acronym for *garbage in, garbage out*. It is a phrase that refers to the fact that computers, operating through logical processes, will unquestionably process erroneous, even senseless, data that are input into the system and still produce an output. This output, though, is usually undesired and often nonsensical. GIGO highlights just how important the human remains in automated operations. Until we are able to develop automation that is intelligent and which can therefore sense that a mistaken input is probably being made and warn the operator of the suspected mistake, the GIGO phenomena will continue to occur.

We can see GIGO in the 2014 story of U.S. Airways Flight 1702, an Airbus 320 departing from Philadelphia to Fort Lauderdale. According to NTSB documents, prior to departing the gate for takeoff, one of the pilots entered the wrong runway into the flight computer. The captain noticed, prompting the other pilot to change the runway information but not the parameters needed for the new runway. At takeoff, as the aircraft accelerated through 80 knots of airspeed, the audio alert in the cockpit announced “retard, retard, retard.” This was an automated audio signal prompting the pilots to reduce thrust setting.

Unfortunately, neither of the pilots knew what the warning meant during takeoff because it was associated with landings. Initially the captain decided to continue with the takeoff and address the discrepancy once airborne, but once in the air realized that something was seriously amiss and decided to touch down again and stop the aircraft. This action resulted in the plane’s tail striking the runway and causing the nose gear to collapse as it hit the ground and skidded to a halt 2,000 feet later, stopping on the runway’s left edge.

Later, Airbus said that the “retard” audio annunciation had sounded because the automated system reverted to landing mode since the parameters needed for the runway were not changed. As we can see, a mistake in the input of data caused the automation to revert to an unexpected mode and produce a surprising response.

It should be noted that, while this section has focused on the interaction of

pilots with automation, everyone else in the safety value chain is also affected. Flight attendants must learn how to operate the increasingly complex systems used for entertainment, cooking, and communication. Aviation maintenance technicians increasingly rely on software systems for reference guidance and tracking task accomplishment. Dispatchers often rely on several software packages that often have changing features due to software upgrades, thus presenting numerous opportunities for confusion and impeding dispatcher SA of numerous flights under their purview.

Lastly, the element of distraction created by smartphones can be incessant and affects every single person on the safety value chain. This is a new source of distraction that has emerged over the past 10 years and which, some claim, is an epidemic. One of the authors of this chapter remembers flying as a pilot of an airliner and being very distracted, at the critical moment of rotation on takeoff, when the other pilot’s cell phone rang loudly on the flight deck.

How many times have you checked your smartphone while reading this chapter? How many times have you answered a text or checked social media while reading this chapter? How have those actions impacted your processing of the concepts in this chapter … the same concepts that could one day possibly save your life? It gives you something to think about, doesn’t it?

HUMAN FACTORS ANALYSIS AND CLASSIFICATION SYSTEM (HFACS)

Since World War II, the study of aviation human factors has developed, promising new tools and a classification system based upon previous research in this critical area. The father of the “Swiss Cheese” model described in the previous chapter, Dr. James Reason, used an interesting analogy when discussing the importance of this topic when he stated “[Human errors] are like mosquitoes. They can be swatted one by one, but they still keep coming. The best remedies are to create more effective defenses and to drain the swamps in which they breed” (Reason, 2005, p. 769).

Starting with Reason’s “Swiss Cheese” model and building upon its framework of latent conditions and active failures, Dr. Douglas Wiegmann and Dr. Scott Shappell developed *Human Factors Analysis and Classification System (HFACS)* for the U.S. Navy in response to increasing human errors and a high accident rate. HFACS is a theoretically based tool for investigating, analyzing, and classifying human error associated with aviation accidents and incidents. The HFACS model has been validated through comprehensive research of 1,020

NTSB accident investigations that occurred over a 13-year period. HFACS uses a systems approach in which human error is seen within the context of a larger problem in the organization.

A review of the "Swiss Cheese" model from the previous chapter (Figures 2-9 and 2-10) is helpful to illustrate the defenses (screens or barriers) that should be set up by an organization to stop the human error chain of causation. The HFACS model uses the same four barrier levels used by Dr. Reason to prevent the accident by controlling:

- Organizational Influences
- Unsafe Supervision
- Preconditions for Unsafe Acts
- The Unsafe Act Itself (the Active Failure)

The HFACS Framework Chart, from Wiegmann and Shappell (2003) (Figure 3-6), breaks down these four barrier levels to their component parts. In the next section, we will discuss the active failure level (unsafe act itself) to determine what control strategies may be effective in combating the inevitable human error dilemma.

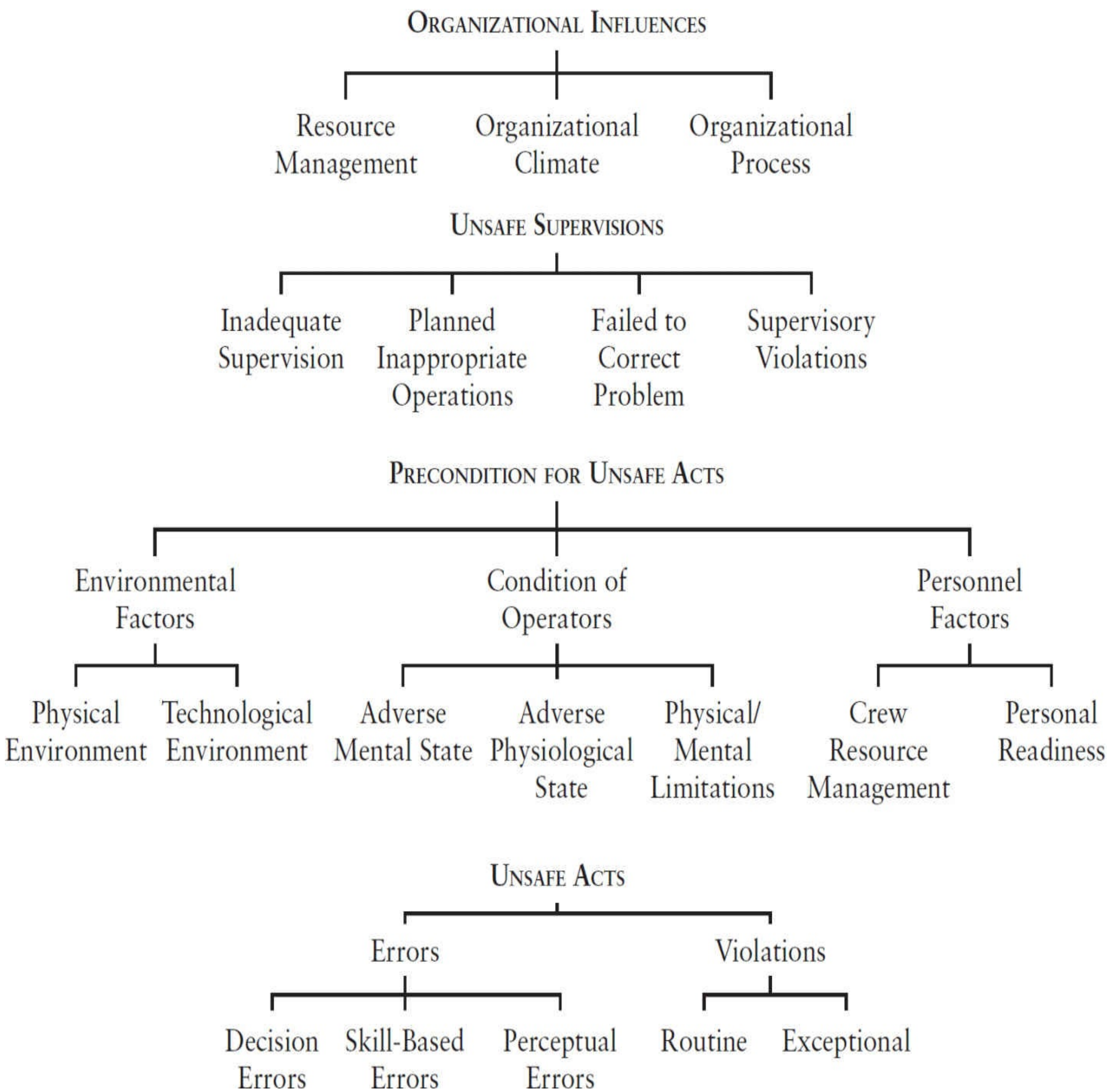

FIGURE 3-6 The HFACS framework four barrier levels. (*Adapted from Wiegmann and Shappell, 2003, p. 71*)

Unsafe Acts—Errors or Violations? Since human error continues to be the largest cause of commercial aviation accidents, the next question becomes, what are these errors and how do we prevent them? The Reason “Swiss Cheese” model and HFACS both describe two general categories of these errors or *unsafe acts*. As pointed out by Shappell and Wiegmann in an HFACS article entitled, “A Methodology for Assessing Safety Programs Targeting Human Error in Aviation” (2009), an error is either an honest mistake or a violation, that is, the willful disregard for the rules and regulations of safety.

Human Factors Analysis and Classification System further describes three types of honest mistakes (decision, skill-based, and perceptual errors) and two types of violations (routine and exceptional). Of course, the primary difference between an error as an honest mistake and a violation is the intent necessary to create a violation. Violations can be routine, habitual, and condoned by the organization, or they can be exceptional or extreme, such as an intentional violation of the U.S. Federal Aviation Regulations (FARs).

Once an accident or incident has occurred, proper utilization of HFACS allows a safety analyst to identify the specific types of human error that occurred at various levels of the organization. Notice once again that the focus of the accident investigation is on "what" happened and specifically "why" it happened in the organization.

The next step in this complex process is to review the multi-level framework of factors potentially contributing to the accident. In the 2009 article, Shappell and Wiegmann proposed five intervention strategies to control human error in these categories:

- Organizational/Administrative
- Human/Crew
- Technology/Engineering
- Task/Mission
- Operational/Physical Environment

The HFACS team has also developed a post-accident tool to investigate the human error problem called the *Human Factors Intervention Matrix (HFIX)*. When plotted against the unsafe acts previously discussed, the five intervention strategies become the HFIX. The HFACS classification method and the HFIX intervention matrix are modern human factors tools which were designed for sophisticated organizations with high-quality data and knowledgeable human factors personnel. It provides a very useful framework for aviation accident investigators to use to study the organization and its role in accident causation due to latent conditions.

ASRS EXAMPLES

Following are some examples from NASA's Aviation Safety Reporting System (ASRS), in the original text submitted, including grammatical errors. These reports demonstrate the complexities inherent in the modern aviation system that make studying human error very challenging.

make studying human error very challenging.

Flight Crew Distraction

Title: Distraction in the cockpit.

As I was approaching gate I shut down the #2 engine (per our Ops Manual). I was momentarily distracted inside the cockpit. There was enough room to make a turn … to gate. I added power on the #1 engine. During the left turn, the jet blast from the #1 engine blew a mechanic off a maintenance stand. It also blew part of an engine cowling off the stand. In future situations, I will … shut down and use a tug to reposition if there is any doubt about jet blast.

Question for the reader: Speculate on what other types of human performance issues may have also contributed to this event but are not mentioned in the narrative.

Flight Crew Fatigue

Title: Fatigue resulting from personal life.

Nav #1 failed en route to airport. VOR/DME A approach in use landing Runway 19. With Nav #1 inoperative, Captain and First Officer decided to have First Officer fly the approach and return aircraft control to Captain when approach completed overhead the airport. In hindsight, this was poor decision making and was likely agreed to due to both pilots being tired. First Officer was nearing the end of a 14-hour duty period. First Officer was briefed 10 hours prior to show time, and between late notice and a new baby, had been awake nearly 20 hours, not eaten in 7 hours. In any case, the Captain was handling radios and forgot to contact Tower, and First Officer relinquished control to Captain overhead airport, thinking they were in a position to turn downwind. First Officer was unable to see the airport. Checklist was still being performed and crew turned downwind overhead [airport], completing the checklist. First Officer was now PNF (Pilot Not Flying) and asked Captain if he called Tower. No reply. First Officer called Tower, who was already asking us what was going on, and at this time, Captain had begun a right turn to correct course. It was too late by now. We turned final, overshot and returned to course, landed. The next morning, after calling in fatigued [and], with adequate rest, it was clear to us that we created our own mess out of a simple instrument error. This goes to show how two tired pilots can over-complicate what should have been a routine flight with a simple VOR out. Recommendations: (1) Call in fatigued before you deteriorate, even if coming in from a day off. (2) When the company knows an early show with a time change is scheduled, [they should] not wait until the last minute to notify a crew member.

Question for the reader: What actions could the first officer have taken to mitigate the fatigue resulting from having a baby at home?

Flight Crew Incapacitation

Title: Pilot incapacitation during flight.

We had started the final descent to the ILS. The Captain was flying the autopilot. ATC gave us a heading

change. I acknowledged, but noticed that the Captain was not turning the heading knob. I repeated the heading change to him, and he reached for the airspeed knob. I asked him if he was OK. He suddenly started shaking all over and … pushing on the rudder and leaning on the yoke. I quickly started to counter his inputs as the autopilot disconnected. When the flight attendant came in, I was still wrestling with the controls. The Captain suddenly went limp, but with his leg still pushing on the rudder. A doctor sitting in First Class came up to help move the Captain out of his seat. In the meantime, I had declared an emergency and requested a turn to final. By then, the Captain had wakened and was fighting the doctor and the Flight Attendant to get back up. [Eventually], they secured the Captain. He required further medical treatment.

Question for the reader: What possible medical conditions could create the behavior exhibited by the captain?

FLIGHT CREW SUBTLE INCAPACITATION

Title: Subtle incapacitation from an infection.

All preflight duties and initial takeoff normal. During the en route climb, I had to remind the Captain to reset his altimeter, as well as insist that he participate in altitude awareness procedures. Small portions of the Captain's speech became unrecognizable. I took control of the aircraft, and advised the Captain that I would fly the remainder of the flight. The Captain agreed, however, his actions indicated that he wanted to participate. Not wanting to create a confrontational atmosphere, I asked the Captain to get the ATIS and the approach plates. These tasks became too difficult for the Captain to accomplish. An uneventful landing was accomplished. The incapacitation was very subtle, with the Captain going into and out of a completely normal state periodically. He wanted to "help" with the flying when he was not lucid. I wish that it had been a sudden and complete incapacitation, as this would have been easier to recognize and deal with.

Question for the reader: How would you determine if a colleague was subtly incapacitated in the middle of a flight operation?

MAINTENANCE MISCOMMUNICATION

Title: Miscommunication from confusing maintenance directions.

A landing gear bushing was significantly over-torqued when three Aviation Maintenance Technicians (AMTs), a Lead Technician, and a Shift Supervisor all misinterpreted a torque setting. I was assigned to work on securing an A320 right main landing gear Side Stay Bushing. I was directed by my Lead Mechanic to work with [two other AMTs]. … We briefly went over the paperwork for this phase and Lead showed us the torque was 500 foot-pounds. … I set the tooling in place, put the nut and locking tab washer in place, spun it down by hand, and then engaged the tooling to begin the final torqueing of the retaining nut. [The other AMTs] read that the final torque setting was 500 foot-pounds and that the initial torque setting was 440 foot-pounds. The torque wrench was set to 440 foot-pounds, shown to our inspector, and then attached to the tooling.

Once the initial torque was reached, we (myself and our Inspector) checked the tab lock positions and it was necessary to advance the position of the retaining nut by close to 1/4 inch to align the lock tab. Once we reached 500 foot-pounds, the tab lock was still not aligned. The Inspector instructed us to back the

collar off and then reapply the minimum torque of 440 foot-pounds and recheck the tab lock position. We continued this through four break/reset sequences with no better luck. We went to the incoming midnight Supervisor and explained the dilemma. He took the paperwork and briefly perused it and then said that we should turn the issue over to the incoming crew. We turned the paperwork over to [the midnight shift Lead] and explained the problem we were having.

He left with the paperwork and returned approximately 15 minutes later to show me that he read that the torque was to be no more than 500 INCH-pounds. The paperwork had "500 lbf.in" in the text. Because of this misinterpretation, the applied torque was 12 times greater than was intended in the operation. There is a difference between the way Boeing and Airbus present this information. Boeing uses "lb-ft" for foot-pounds and "lb-in" for inch-pounds. Airbus references foot-pounds with "LBF.FT" and inch-pounds with "LBF.IN". I believe that "LBF.IN" is very confusing and led to our mistake in applying the improper torque for the job. Perhaps "LB.IN", or spelling out "foot-pounds" or "inch-pounds" would be clearer.

Question for the reader: If you were a safety manager with responsibility over this maintenance operation what actions would you take based on this report?

Air Traffic Control Deviation

Title: Deviating from standardized phraseology.

… we finally contacted Departure passing through approximately 6,500 feet climbing. The Controller's response was a hurried, 'Roger, maintain 2-3-0.' The Captain responded, 'Roger, 2-3-0.' At this point, flight level 230 was selected on the aircraft's MCP (Mode Control Panel). … It was at this point that the Controller said that we had been assigned 8,000 feet. The Captain replied that we had been assigned flight level 230. The Controller's response was, 'I said two-hundred thirty knots, sir.' … Those numbers can imply heading, altitude or airspeed.

Question for the reader: How did both the air traffic controller and the flight crew contribute to this grave miscommunication?

CONCLUSION

Aviation professionals are key members of the safety value chain that keeps accident rates low in commercial flight operations. Although humans are largely responsible for commercial aviation's excellent safety record, human errors nonetheless cause or contribute to most accidents. Moreover, the rate of pilot-error accidents shows no sign of decreasing, while weather-related crashes are declining, and aircraft component failures are rarely the sole factor in serious accidents. Furthermore, accident and incident data analyses indicate that if only a portion of human-error problems can be solved, substantial reductions in accident risk can be attained.

Another concern among human-performance experts is that the increased level of automation in professional settings may create a generation of workers

level of automation in professional settings may create a generation of workers whose basic flying “Stick and Rudder” skills deteriorate from lack of practice. If such manual abilities ever become needed because of automation failure/degradation or unusual aircraft attitudes and conditions that automation cannot handle, the pilot may not be up to the challenge. Manual piloting skills may have degraded because of the use or overuse of automatic flight systems in lieu of hand flying or because of the lack of training and practice on certain maneuvers and skills.

The increasing complexity of technology, airspace, and legislation means that pilots must be complete knowledge masters of their realm. Automation does produce the gains in efficiency and SA that prompted its development in the first place, but only if the operators are proficient with the automation during both normal and emergency situations. Additionally, pilots must possess the soft skills of effective communication, leadership, and followership which will be discussed in the next chapter. These are very involved skills that require an open-minded approach, a willingness to learn, and lots of practice. What we consider an expert pilot has changed in the past century from someone who can make accurate decisions without proper information to someone who knows how to seek out accurate information and apply it via automation in a team environment.

Human error on the flight deck can never be totally eliminated. The same holds for human error by dispatchers, flight attendants, ramp personnel, aviation maintenance technicians, air traffic controllers, and anyone else who forms part of the commercial aviation safety value chain. However, through judicious design, constant monitoring of accidents, incidents, and internal reports, and the aggressive use of reporting systems such as NASA’s ASRS, different means of preventive safety measures can be created. Air transportation enjoys an excellent safety record today largely because no part of the system is ever allowed to rest. Lack of SA has been identified as a contributing factor in many accidents and incidents, but the reasons for its breakdown, such as cognitive errors or fatigue, must be probed and understood through HFACS and other investigative means to obtain continued safety gains. Modern airline training tools can greatly improve pilot performance through enhanced ADM and a clear understanding of human factors principles to identify and control human error.

Numerous errors grow out of our natural cognitive processes. The tendency to take “thinking shortcuts” makes our mind very susceptible to a host of subtle influences and biases, such as false expectancies of what is about to happen. We are left to wonder how the human race has made it as far as it has, particularly when we contemplate that these cognitive errors or biases can work in concert

with each other. Our success has been in spite of our failings because the brain is usually a great match for the tasks we face. However, that answer is not good enough when dealing with high-reliability operations such as those of aviation.

The next chapter in this book will expose the flipside of this chapter by addressing the reasons humans, despite our fallibility, add greatly to the safety value chain and are not just the problem, but also the solution.

KEY TERMS

Automation
Automation Surprise
Aviate, Navigate, Communicate
Cognitive Error
Crew Resource Management (CRM)
DECIDE Model
Embracing Our Blunders
Error Chain
Fatigue
Fitness for Duty
Garbage In, Garbage Out
Goldilocks Zone
High-Consequence Operation
High-Reliability Organization
High-Risk Industry
Human Factors
Human Factors Analysis and Classification System (HFACS)
Human Factors Intervention Matrix (HFIX)
Human Performance
Information Overload
Miller’s Law
Mode Confusion
Multicausality
Pilot Error
Safety Value Chain
Situational Awareness
Soft Skills
Sterile Cockpit Rule

Sterile Cockpit Rule
Threat and Error Management (TEM)
Unsafe Acts

REVIEW QUESTIONS

1. Do you think that aviation can be or ever will be devoid of human error?
2. What are the three reasons why people make poor decisions? How does this relate to commercial aviation safety?
3. Describe the difference between human factors and human performance.
4. Do you think error chains always have a clear starting point? Why or why not?
5. How do you think the "pilot error" myth affects the attitude of pilots in the skies today?
6. Describe two different types of cognitive errors.
7. Explain what is meant by the so-called "goldilocks" zone of workload with regards to optimal SA.
8. Give a detailed explanation of fatigue and how it affects a flight crew.
9. What is situation awareness?
10. In your opinion, which of the following human–automation interaction outcomes poses the largest threat to commercial aviation safety: automation surprise, mode confusion, or garbage in, garbage out? Defend your answer.
11. If you were an air safety investigator, how would you use HFACS and HFIX to address a miscommunication between a flight attendant and an aviation maintenance technician that results in the wrong type of seat belt being installed on a flight attendant seat?

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Professionalism in aviation, ASRS examples, and case study: http://www.ntsb.gov/

CHAPTER FOUR

HUMANS AS THE SOLUTION

LEARNING OBJECTIVES

After completing this chapter, you should be able to

- Depict the opportunities of working in groups versus working individually.
- Explain the nature of personal responsibility in professionalism.
- Understand the major components and overall theme in CRM.
- Describe the major elements of each generation of evolution of CRM.
- Depict the existing evidence that CRM produces results.
- Provide a personalized definition of leadership and of followership.
- List actions of capable leaders and of effective followers.
- Explain how a captain should encourage participation in his or her authority.
- Describe how followers can practice assertiveness with respect.
- Discuss the relevance of transcockpit authority gradients to CRM.

INTRODUCTION

The previous chapter exposed the myriad aspects of the human condition that make us so prone to making mistakes as individuals, in groups, and as organizations. After reading the previous chapter it may seem that complex enterprises, such as commercial aviation, are impossible to operate with any hope of safety, much less efficiency. Yet day after day we see tens of thousands of contrails over the skies of some countries, and years go by without a single major accident in scheduled airline aviation in those same skies. Knowing the human tendency to err, how is such an achievement ever possible?

In this chapter, we look at how humans are not only the challenge as sources of errors, but can actually be effective as the solution to the challenge, serving as agents of accident prevention. Humans actually form the safety value chain that keeps commercial aviation flying. At the individual level we learn both technical and soft skills designed for error management and then leverage those skills through a professional attitude in a team environment. Doing so we can actually

produce less net errors than if we operate alone. That is a key principle behind a team approach to safety. Figure 4-1 shows such an operation, where a team of seven highly qualified and trained personnel from Singapore Airlines is performing maintenance functions on an Airbus 380 engine, on the ramp, no doubt under significant schedule pressure.

FIGURE 4-1 Working on a Singapore Airlines Airbus 380 engine. (*Source: Wikimedia Commons*)

However, teamwork only results in better safety than individual work if the members of the team master the technical requirements of their position and can properly interface with the other members of their team. The key to any team is the safety contribution of each individual member. The true output of teamwork cannot be achieved unless each member is striving for excellence. Efficiency and safety of aircraft operations can be traced back to the use of *influence* by leaders to affect the behavior and attitude of subordinates. Leadership skills are not genetic; they are learned through education and honed by a professional commitment to self-improvement.

This chapter starts by examining individual excellence through the lens of

professionalism to include how to obtain peak individual performance and how to add value to safety. The chapter then explores the origins, evolution, and components of CRM, then finishes with a case study and ASRS narratives that illustrate the principles and practical aspects of the chapter.

PROFESSIONALISM IN AVIATION

The topic of professionalism has received significant attention from the NTSB, the FAA, and industry trade associations over the past decade. Some have defined professionalism as an employee's "depth of commitment to excellence," others as "doing the right thing even when no one is looking." This book promotes the notion of *empowered accountability* of all employees as a key aspect of professionalism for addressing safety. The expression refers to the need to encourage each aviation employee to actively seek out hazards, to report the hazards so that they can be addressed, and to be held accountable if they chose to not act on the hazard. The concept is meant to instill the notion that everyone has a role in accident prevention.

Regardless of how professionalism is explained, the core concept is one of striving to ensure that tasks are completed as best as possible and, therefore, we see instantly that professionalism is a key ingredient in the safety value chain of commercial aviation. The importance of the concept comes through loud and clear in the following excerpt from Stephen Coonts' aviation book, *The Intruders*:

> *This thing we call luck is merely professionalism and attention to detail, it's your awareness of everything that is going on around you, it's how well you know and understand your airplane and your own limitations. Luck is the sum total of your abilities as an aviator. If you think your luck is running low, you'd better get busy and make some more. Work harder. Pay more attention. Study more.*

After a series of incidents in the last decade, the NTSB conducted a 3-day public forum in May 2010 to focus on pilot and air traffic controller professionalism as a safety issue. Among the incidents discussed were the following due to each having significant ties to a lack of professionalism:

- Comair Flight 5191 in Lexington, Kentucky, where the aircraft took off on the wrong (short) runway in 2006.
- Colgan Airlines Flight 3407 in Buffalo, New York, where the aircraft stalled and crashed short of the airport in 2009.
- The fatal midair collision over the Hudson River between an air tour helicopter and a fixed wing general aviation aircraft in 2009. The air traffic

controller was engaged in personal business at the time.

There are accidents waiting to happen all around. We must keep our eyes open to warning signs that could indicate that an accident sequence is commencing or continuing. In fact, all of our senses need to be alert, as we also need to use our ears to listen actively and make sure we clearly understand the verbal information we are receiving. As humans, we have a tendency to passively absorb information without questioning the message attached to it. To be professional means to be vigilant and critical in all areas of our work to ensure a hazard-free workplace.

Achieving Peak Individual Performance

This section dives a bit deeper into certain conditions that can allow us to achieve peak performance. Each employee in commercial aviation should recognize that he or she can have a profound impact on the safety of a given flight and that impact is often associated with how well he or she exhibits professionalism. The good news is that when we see humans as the solution and not the problem, we realize that the contents of this chapter all relate to actions we can take that are often fully within our control, to add value to the safety of an operation.

Let us start with the physical condition of each employee. We should each be in physical shape in order to obtain peak cognitive and physical performance. Numerous medical sources state the need to perform up to 5 hours of *aerobic activity* per week. In addition to the well-known benefits that such activity has on sleep and cardiopulmonary fitness, 5 hours of aerobic activity per week also produces improvements to thinking, verbal memory, and attention (Johns Hopkins, 2006), plus benefits to memory, reaction time, visuospatial acuity, and increase in the distribution of oxygen and glucose via blood flow to and through the brain (O’Dwyer, Burton, Pachana, & Brown, 2007), and may help stimulate the growth of new neurons within the brain (Dana Alliance for Brain Initiatives, 2008). The benefits of aerobic activity thus have direct impacts on our human performance and therefore directly influences how much we benefit the safety value chain.

We cannot address peak performance without making a serious mention of the horrible, direct, and often deadly impact created by *fatigue* in aviation. Fatigue can be mental, physical, or both, and is a feeling of tiredness. It differs from sleepiness in that it is a more long-term condition. Causes include excess physical activity, lack of sleep, medications, and health conditions such as

anemia, anxiety, and depression. Being fatigued has serious implications in the aviation arena, as workers are more prone to make mistakes when they are in this extreme state.

Fatigued ramp agents have walked into spinning propellers on the ramp, resulting in gruesome and immediately fatal injuries. Fatigued air traffic controllers have forgotten about aircraft converging on each other resulting in fatal head-to-head midair collisions. Fatigued dispatchers have passed along incorrect weights and center-of-gravity calculations to flight crews, resulting in improper pitch trim settings that made aircraft uncontrollable on takeoff. The list is truly long of how this silent killer has acted against commercial aviation safety. Fortunately, we can take actions as employees to significantly mitigate the effects of fatigue, and thus, ensure that we operate as close to peak performance as possible.

Aviation professionals must always remember their ethical obligation to arrive for a period of work fit so that they can perform at their best. Doing so may mean not staying up to watch a movie with a spouse the night before reporting for duty, hiring a babysitter to tend to a crying baby the night prior to a week-long trip, wearing earplugs when sleeping in a hotel, not drinking alcohol in the hours prior to going to bed to prevent disruption in the sleep cycle, not answering a phone call in the middle of a designated sleep period, and not going to see a famous museum during an overnight at Rome that requires sacrificing sleep. It also may mean knowing when to call-in-fatigued in order to ensure that the safety of a flight is not compromised.

An organization is also responsible for an individual being able to reach his or her peak performance. It is not just all up to the employee! Organization policies set the framework within which employees can perform at their peak. Fatigue Risk Management Systems (FRMS) aim to alleviate the effects that workers feel from fatigue based on the application of peer-reviewed scientific research. An FRMS is an effort to move past typical programs that mitigate risk by limiting the number of hours worked to developing a comprehensive plan to help workers. Prior to the introduction of FRMS the policies had surprisingly been the same for over 50 years. The FAA published Advisory Circular 120-103A, titled “Fatigue Risk Management Systems in Aviation Safety,” in 2013 to provide guidance on how to implement the requirements of part 117 of Title 14 of the Code of Federal Regulations, which covers FRMS. These new guiding documents placed new emphasis on fatigue and also changed how the commercial aviation community worked to manage flight crewmember fatigue.

When designing an FRMS, management should develop policies and

procedures that focus on the carrier's specific kind of operations and type of operations. There should be a commitment from leaders to reduce fatigue and improve flight crew alertness due to its direct effect on safety. They can do this by:

- Incorporating a letter from the Director of Operations level management acknowledging their commitment to managing and mitigating fatigue to improving flight crew alertness.
- Establishing and incorporating the air carrier's concept of a corporate *Just Culture* or *Safety Culture*.
- Establishing and incorporating an open communications policy for reporting fatigue-related issues.
- Establishing and incorporating a fatigue reporting system.
- Defining how an event will be evaluated for potential fatigue involvement as well as defining an overview of the methodology for conducting a detailed root-cause analysis.
- Providing for protection of privacy and methods to protect the employee from adverse actions that would discourage reports of fatigue. The air carrier will develop and implement a process for reviewing reports and the actions taken to reduce flight crew fatigue exposure.

An FRMS also encourages a company to create education awareness training programs for fatigue. Content should include the basics of fatigue, effects of operating with the condition, and countermeasures, prevention, and mitigation. Additionally, there should be an incident reporting process to help prevent performance errors attributed to fatigue. By engaging everyone in the company, from the ramp workers to the CEO, humans can act as a defense against the safety consequences of operating with fatigue.

Empowered Accountability

Each employee in commercial aviation is a potential sensor, meaning that everyone can be trained and encouraged to actively seek hazards and report the hazards in order to promote safety. Furthermore, they should be held accountable if they missed opportunities to act on hazards. That describes the concept of empowered accountability. After all, most accidents are preventable. Granted, some very few accidents probably are not preventable. A somewhat farfetched example of an unpreventable accident would be the crash of an

airliner due to a meteorite strike. In addition, some rare accidents inevitably must result when one takes calculated risks where the probability of an accident is very, very low. For example, we routinely fly out of airports where birds congregate during seasonal migrations, or in some cases, over prolonged periods of time. Extensive measures can be and are routinely taken to discourage birds from congregating around airports, but in the final analysis, the risk of an accident caused by birds cannot be reduced to zero without simply grounding all aircraft or birds.

Many accidents that may seem unpreventable at first glance actually are preventable. Others that occur because of a calculated risk about operating with a hazard can be reduced in number or severity by implementing appropriate risk-mitigating actions. Consider, for example, an accident that results from a commercial airliner striking a deer during a pre-dawn departure on a cold winter morning from an airport that borders a forest. Such an occurrence may seem like just bad luck with nothing that can be done to prevent the collision, especially since it was dark when the event occurred. However, at some point, someone in the deer-strike sequence likely had the ability to prevent or reduce the probability of the collision.

Perhaps it was another pilot who nearly hit a deer a month ago and could have contacted the airfield manager and furnished information that resulted in an airport Notice to Airmen (NOTAM) or filed a safety report with his or her company. What about the aviation maintenance technician who was working at 3 am on the ramp the day of the accident and who noticed deer run past him and toward the runway but did not feel an urge to ensure someone was addressing the issue? Maybe it was the airfield manager who knew there was a hole in the perimeter fence but was waiting for the spring season when the snow melts to repair the damage. Perhaps it was one of the pilots of the departing aircraft who knew that deer sometimes encroach on the field around the time of the planned departure, but did not practice any risk management when considering the chance of a deer strike.

Each one of those individuals recognized an operational hazard and elected not to take action. Each individual had a unique opportunity to interrupt the accident sequence, but didn’t. They could have added to the safety value chain but made a decision not to do so or did not even think about doing so. Complacency comes in many forms, but it always reflects an unprofessional attitude that fosters risk. Properly trained and motivated employees will immediately and decisively act on such hazards and are thus a key means to preventing such hazards from producing accidents. Such an attitude constitutes the professional behavior that this chapter tries to encourage.

When viewed through the lens of professionalism as a key means to promote safety, each of the individuals in the hypothetical deer-strike scenario is accountable for not pursuing action to address the perceived hazard. Perhaps without being aware of it, each was empowered to act but failed to do so. A strong sense of professionalism would have created motivation for action, but such was not the case. Instead, potential actors remained mere spectators to a threat. It is as if they were passengers, so to speak, to the unfolding situation. However, it is likely that none of the individuals in the event sequence, other than the accident pilots, will be held accountable. It is quite possible that the pilots also will not face any consequences, given that many managers will likely believe that there was no opportunity to interrupt the sequence of events.

Everyone's failure to do something illustrates why empowerment to act for safety must be taught throughout an aviation organization and why positive actions influencing safety must be rewarded. The responsibility to support safety by positive actions must be clearly understood by each member of the organization; it must be part and parcel of each member's sense of what it means to be aviation professionals.

How much training, if any, does a typical customer service representative at an airport gate, a ramp agent, a dispatcher, or a flight attendant receive on the concept of empowered accountability? Many of us in a position to recognize and break a developing accident sequence remain ignorant of how accidents occur in the first place, which is the purpose of including the second chapter in this book. Mentally we are *passengers* in our own industry. It will not be trivial to reverse this situation.

Despite the need for accountability, some industry leaders have not fully embraced the potential gains that such an attitude brings to safety. Leaders must ensure that employees are trained in the causes of unsafe acts and their relationship to aviation accidents. We must all learn how to recognize and properly report perceived unsafe acts and conditions. We must also understand that we will be held accountable if we could have prevented an accident, serious incident, or even just an unsafe event, but instead opted for complacency, thus allowing an accident chain to propagate.

CREW RESOURCE MANAGEMENT (CRM)

Here is an interesting question to ponder: if we all make mistakes, then what is the advantage of having two pilots over one pilot on the flight deck of a commercial airliner? After all, will two pilots not make twice as many mistakes

during a flight as a single pilot? Let us see if the reader can answer the question by the end of this chapter.

While the past chapter shared some of the seemingly countless ways in which humans fall prey to errors and biases, this chapter focuses on how the human spirit can combine with science and ingenuity to build better ways of managing our tendency to err and be biased. One major accomplishment toward that goal in aviation safety has been the development of *Crew Resource Management (CRM)*. Stated succinctly, CRM is a philosophy for mitigating error and maximizing efficiency when operating an aircraft that leverages the presence of more than one individual.

The concepts of CRM have wide applications to many facets of life and are used in many industries. In aviation, the people involved in CRM are primarily pilots, but also must involve flight attendants, external crewmembers, even passengers. Essentially we are referring to any people or material that can have an impact on the outcome of flight. All such people and material are considered resources, and how we coordinate the use of such resources is the practice of CRM. The U.S. Air Force offers a very useful explanation by stating, “CRM training is a key component of a combined effort to identify and manage the conditions that lead to error” (USAF, 2008, p. 5). Notice how the Air Force mentions CRM as a key, but not the only, component in addressing the conditions that lead to error. We previously mentioned individual accountability for our own performance as another important means, but now we are discussing the team aspects of safety.

To reduce error, researchers have focused efforts on understanding the human factors endemic to aircraft operations. Specifically, psychology has made major inroads in detecting how errors are formed at the individual cognitive level. However, such efforts do not address errors that arise due to crewmembers interacting with each other, be it through verbal exchange, nonverbal communication, or assumptions of what a fellow crewmember knows or actions being undertaken. CRM was developed precisely to address such needs. Other advances have been made in areas related to CRM processes and in how we train such processes during initial and recurrent flight training. Yet, the amazing fact remains that CRM is *not* universally embraced by pilots throughout the world. The world is a large place and only a segment of the pilot population work for commercial air carriers. Even within commercial aviation there are some pockets around the globe where CRM principles are not followed. However, those pilots who embrace CRM can significantly increase the safety of a flight, as will be depicted in this chapter. Most commercial aviation operations throughout the world have, to some extent, incorporated CRM training into the pilot curricula

and even into how they train other employees.

Fundamental CRM skill sets include leadership, communication, crew coordination, judgment, and decision making. Each skill set presents a seemingly bottomless ocean of knowledge for use in both routine and abnormal flight conditions. CRM can be seen as a human victory over the potential errors that can surface in the complex aviation system. The ingenuity and creativity of talented minds in the accident prevention movement created CRM as a means for preventing, minimizing, and correcting the natural human tendency to commit errors before such errors result in disaster.

EVOLUTION OF CRM PRINCIPLES

CRM is so embedded in the minds of most commercial aviation professionals today that it is hard to imagine a world without it, but such a world did exist, and we are by no means finished with the evolution of CRM development. We must remember the roots of aviation to help visualize what flight operations looked like before CRM. In October 1927, Pam American Airways flew a Fokker F-7 Trimotor from Key West to Havana in what became the first U.S. commercial flight. Since then, individuals and certain crews have used the principles of CRM, although they may not have called it CRM, but it has not been until the last 30 or so years that the principles have been lumped together and taught as part of CRM programs.

In the 1920s and 1930s, most aviators were associated with barnstorming and airmail runs and, thus, were considered brave, even daring. The fatality rate was quite high in those early days and it took a special kind of person, often male, to undertake the profession. Although women aviators existed as the era of commercial aviation began, most women in the aviation profession were associated with flight attendant positions and were called “Skygirls.” The 1930 Boeing Air Transport Manual provided the following guidance that today sounds humorous: “Skygirls should render a rigid military salute to the captain as they go aboard and deplane … there is no real need for conversation or contact.” Such was the perspective of pilots as being significantly higher in social status from other airline employees, such as flight attendants or ramp support personnel. The opinions of employees were neither expected nor particularly welcome by many pilots, although exceptions undoubtedly existed.

The high regard and even awe that employees used to have of captains were partly a product of the heritage of aviators and also partly due to the nautical equivalent, the ship captain, where the captain’s word was considered law. The situation remained for several decades. Although group dynamics had been

studied as an offshoot of crew performance and accident investigation in the 1940s and 1950s, it was not until the Apollo era of spaceflight in the 1960s that the topic came under serious consideration when NASA studied the group dynamics of astronauts.

As the Apollo program was winding down, awareness that something was wrong in commercial aviation started to grow slowly at first, and would eventually lead to the CRM movement. In 1972 a Lockheed L-1011 operating as Eastern Airlines Flight 401 flew into the Everglades in Florida as all members of the flight deck crew were focused on a burned-out light bulb. During the troubleshooting, no pilot had been assigned the task of flying the aircraft and, although an altitude discrepancy was noticed by air traffic control, the flight gently descended without the crew noticing the critical *controlled flight into terrain (CFIT)* problem.

That same year in Europe, a Hawker Siddeley Trident operating as British European Airways Flight 548 entered a deep stall 3 minutes after departing from London and crashed, killing 118. The accident was a result of dysfunction in crew coordination and, together with the Eastern 401 accident, served to catch the attention of aviation safety professionals that something was seriously wrong with the human element in commercial aviation safety.

In response to those and other serious accidents, the Flight Safety Foundation (FSF) and the International Air Transport Association (IATA) convened conferences in 1974 and 1975 in Virginia and Turkey to address the concern of human causes to commercial aviation accidents. The concern was growing within the awareness of aviation safety professionals but was not necessarily high on the consciousness of the public, but that would soon change.

Just 2 years after the IATA conference, two Boeing 747 aircraft collided in foggy conditions on the island of Tenerife, Spain, causing the worst loss of life in any single accident in the history of commercial aviation. That terrible record stands to this day. The collision was a result of coordination breakdown, the *false expectancy* of a takeoff clearance in the mind of one of the captains, and the lack of assertiveness on behalf of crewmembers who did not question the captain’s decision to takeoff without a clearance. A total of 583 people lost their lives in that tragic accident.

One year later, in 1978, one more accident occurred that would be the final straw that broke the camel’s back. A Douglas DC-8 operating as United Airlines Flight 173 crashed near Portland, Oregon, after running out of fuel, killing 10 occupants. The accident resulted from the captain focusing too heavily on preparing the cabin for an emergency landing due to a gear malfunction, while

neglecting both the fuel state and the increasing concerns of the other flight crewmembers who were rightfully worried about running out of gas.

The string of accidents all occurred due to poor communication and coordination by the humans operating the flights so, building on the momentum of the safety conferences in Virginia and Turkey, NASA decided to host a series of conferences in 1979 out of which the CRM concept was officially born. At that time the term stood for *Cockpit Resource Management* and was narrowly focused on flight deck crewmembers, often comprised of two pilots and a flight engineer in those days. In hindsight we consider the CRM principle that was born in 1979 as the first generation of CRM, since much was to happen over the next few decades that would shape the evolution of the modern CRM of today.

Crew Resource Management has evolved considerably since then. Many experts claim that we are now living in the sixth generation of CRM, although several purport that we are already in the seventh generation, although we do not yet realize the shape that the seventh generation is taking. The *first generation of CRM* in 1979 focused on changing individual behavior, primarily that of the captain, so that input would be incorporated from other flight deck crewmembers when making decisions. Many of the captains of that era were born in the 1920s and were veteran combat aviators from World War II. The first generation of CRM has since been humorously referred to as “charm school” in that by trying to change the behavior of captains it was often perceived as trying to turn gruffness into charm.

Around 1980 and 1981 two airlines lead the CRM movement globally, United Airlines and KLM Airlines. Both programs stressed management and personality styles. As one might imagine, many captains felt personally insulted by such initiatives and were very defensive when told that they were exhibiting accident-prone behavior and therefore had to change. Can you imagine a captain of that era, who may have shot down enemy aircraft and been labeled a hero, suddenly told that he was a problem?

As airline accidents with CRM components continued to happen, such as the very dramatic crash of a Boeing 737 operated as Air Florida flight 90 during a winter storm in Washington, D.C. in 1982, the industry and government continued to cooperate to shape and evolve CRM. In 1984, heavily influenced by the leadership of Dr. John Lauber, CRM was defined in such a way that was accepted by stakeholders as “the effective utilization of all available resources—hardware, software, and *liveware*—to achieve safe, efficient flight operation.” Liveware, in this context, alluded to humans.

As a result of these efforts, around 1984 the *second generation of CRM* took

shape. Instead of focusing on changing individual behaviors, CRM now went deeper in an attempt to change attitudes and focus more on decision making as a group. This generation also recognized that CRM should involve more than just flight deck crewmembers and that others, such as flight attendants, often possessed key information that should be communicated to the flight deck to prevent accidents. Special emphasis was placed on briefing strategies and the development of realistic simulator training profiles known as *Line-Oriented Flight Training (LOFT)*. Figure 4-2 shows an airline flight crew operating a sophisticated modern Fokker 70/100 simulator to fly an approach. When combined with realistic situational scenarios, such simulators host LOFT sessions that are grueling but extremely important for pilots to learn both technical and CRM skills, and how both skills need to work together to assure a safe outcome to the flight.

FIGURE 4-2 Modern flight simulator capable of performing a LOFT. (*Source: Wikimedia Commons*)

By 1985 only four air carriers in the United States had full CRM programs: United, Continental, Pan Am, and People's Express. American and the U.S. Air Force Military Airlift Command soon introduced CRM programs, and the U.S. Navy and Marine Corps were on the verge of starting CRM programs. In 1989, a very serious accident happened that provided irrefutable proof that CRM principles worked. A DC-10 operating as United Airlines Flight 232 experienced the uncontained failure of its #2 engine, resulting in a loss of normal flight controls. The captain ably coordinated flight deck and cabin resources to perform a controlled crash of the aircraft at Sioux City, Iowa. The resulting crash killed 111, but there were 185 survivors who likely would not have survived at all had it not been for the CRM prowess of the crew.

In the early 1990s the *third generation of CRM* took hold, which deepened the notion that CRM extended beyond the flight deck door. That generation saw the start of joint training for flight deck and cabin crewmembers, such as for emergency evacuations, placed emphasis on the role of organizational culture, and also started exploring how flight deck automation was increasingly a key component of communication and coordination protocols for pilots. Some vocal pilots voiced concern that CRM was becoming too diluted by extending it past the flight deck with all the increased emphasis on using external resources. Around 1992 CRM also saw itself being exported to the medical community to address similar group dynamics events associated with medical error in both routine and emergency care at hospitals.

Around the mid-1990s the *fourth generation of CRM* was introduced, which promoted the FAA's voluntary *Advanced Qualification Program (AQP)* as a means for "custom tailoring" CRM to the specific needs of each airline and stressed the use of Line Oriented Evaluations (LOEs). This generation also fostered the pairing of crew behaviors to checklists and advocated the integration of CRM training directly into technical training versus as a stand-alone initiative. In 1998 the FAA made CRM training mandatory for U.S. Airlines through FAR 121.404. It should be noted that this was 19 years after NASA's effort to start what became CRM, which shows the not uncommon delay in implementing new regulations that promote safety.

Around 1999 the *fifth generation of CRM* took hold, which reframed the safety effort under the umbrella of "error management," modified the initiatives so as to be more readily accepted by non-Western national cultures, and placed even more emphasis on automation and, specifically, automation monitoring. Three lines of defense were promoted against error: the avoidance of error in the first place, the trapping of errors that occur so that they are limited in the damage

they create, and the mitigation of consequences when the errors cannot be trapped. This generation also promoted the use of incident data in addition to accident data. This generation was influenced by the now NTSB Member Robert Sumwalt and two co-authors who studied the ASRS database and in 1997 published “What ASRS Data Tell about Inadequate Flight Crew Monitoring.” In the paper they were quoted as stating, “One pilot must monitor automated flight systems 100% of the time” and mentioned that “Monitoring … is the lifeblood of safe flight operations.”

At the start of the 21st century, the *sixth generation of CRM* was formed, which introduced the *Threat and Error Management (TEM)* framework as a formalized approach for identifying sources of threats and preventing them from impacting safety at the earliest possible time. Sophisticated and elaborate TEM models were introduced for intervention and rely heavily on human factors knowledge for improving safety in aviation.

Threats can be any condition that makes a task more complicated, such as rain during ramp operations or fatigue during overnight maintenance. They can be external or internal. External threats are outside the aviation professional’s control and could include weather, a late gate change, or not having the correct tool for a job. Internal threats are something that is within the worker’s control, such as stress, time pressure, or loss of situational awareness. If the threats are not managed properly they can impact safety margins and cause errors, which are mistakes that are made when threats are mismanaged. *Errors* come in the form of noncompliance, procedural, communication, proficiency, or operational decisions.

The TEM framework recognizes the relationship between threats and errors. In fact, many airlines are moving away from CRM training and putting more emphasis on TEM instead. They feel that CRM is too broad and open to too much interpretation. If aviation professionals can identify the threats and manage them, then they can directly mitigate human errors. Safety procedures are in place to resist some risks from having harmful outcomes, such as inspections and operational checklists, but some errors do not have a buffer. However, we as workers also have the opportunity to resolve the error before it leads to a negative impact.

To assess the Threat and Error Management aspects of a situation, aviation processionals should:

- Identify threats, errors, and error outcomes.
- Identify “Resolve and Resist” strategies and counter measures already in

place.

- Recognize human factors aspects that affect behavior choices and decision making.
- Recommend solutions for changes that lead to a higher level of safety awareness.

Central Theme of CRM

The evolution of CRM has been long and productive, and will undoubtedly continue into the future. Throughout it all, a central theme has emerged where leaders and subordinates work together in a way that maximizes efficiency and safety. Although many important concepts are covered in CRM training, the one most overriding idea is that of creating an environment that is most suited for the proper types of communication and coordination.

The importance of a supervisor or senior employee setting the proper tone for his or her coworkers cannot be overstated in order to achieve the proper safety environment. This is particularly true if the supervisor or senior employee promotes inquiry and assertion by working to open the lines of communication. Of course, the concept of assertion not only depends on the supervisor or senior employee setting the proper tone for a flight. Other employees must also be encouraged to inquire when someone feels that something is wrong and to advocate their concerns in such a fashion that does not diminish the supervisor or senior employee's authority, but that instead uses the supervisor or senior employee as a catalyst for solving problems.

Henceforth in our discussion we will refer to the supervisor or senior employee as the captain, given that so much of CRM development has focused on the captain of an aircraft as the leader of the airborne team. However, the reader is urged to remember that the concepts being discussed transcend the flight deck and apply throughout commercial aviation employee ranks.

This central theme of CRM of which we speak is best expressed in two elements:

1. *Authority with participation*
2. *Assertiveness with respect*

Participation. Authority is defined for purposes of this text as the ability to influence others as a result of the office or rank that one occupies. The captain cannot be everywhere at once, nor aware of all processes that affect the aircraft

at any given time. Furthermore, numerous tasks sometimes need to be accomplished simultaneously. Thus, the captain must be able to effectively delegate authority to different crewmembers at different times, while retaining overall responsibility for the safety of the aircraft and its occupants. This process requires that the captain place trust in the training and the capabilities of the crewmembers that are being delegated tasks.

In the context of CRM, the captain should attempt to perform participative leadership, which is a leadership style in which crewmembers are encouraged to be part of the decision-making process while being given full autonomy to accomplish specifically assigned tasks. One of the many challenges faced during the introduction of CRM was that changing someone's leadership style, much like attempting to change personality, is an extremely difficult undertaking once the style has been firmly in place for some time. The element of participation in leadership decisions carries the potential risk of influencing how people perceive the authority of the leader. Flying an aircraft does not employ democracy for decision making! It is highly desirable that a captain be a strong leader, which in the CRM context is defined as fostering crew participation without diminishing one's perceived authority.

Captains are vested by their company and by aviation regulations with the authority to influence others as the designated leaders of their crews. Discussions on the concept of captain's authority are prevalent on professional flight decks across the world. It is quite common these days to hear flight crews bemoaning the perceived erosion of captain's authority, as is illustrated in the first ASRS example later in this chapter.

Much of the early culture and processes in aviation were modeled from maritime history. As such, the concept of deference to a captain's authority originated in the maritime world, where it was discovered long ago that ships could not be governed democratically without catastrophic consequences. Not too long ago, maritime law actually expressed the matter succinctly by stating, "The captain's word is law." Further increasing the sense of an airline captain's authority was the tremendous respect, if not awe, that most people had toward the early pioneers of aviation.

As air travel became increasingly safe in the 20th century, the public started losing some of its awe for pilots. As the number of aviators swelled into the tens of thousands and the accident rate dropped dramatically in the 1960s and 1970s, the public sentiment toward pilots shifted. Aviators were no longer seen as minor gods by the general public and, more to the point, by fellow aviation professionals such as ground support personnel and cabin crewmembers. The

increasing accessibility of air travel following the 1978 Airline Deregulation Act in the United States caused a further reduction in the perceived prestige of the airline pilot profession.

Pilot acceptance of CRM during the 1980s was hampered, partly, by captains who viewed the movement as an attack on their authority. In the years since the September 2001 terrorist attacks, pilot unions have voiced concern that security measures have further diminished the captain's authority. Security decisions are often made for a flight by government officials without consulting the captain, thus effectively usurping the captain's authority in such matters. Furthermore, the terrorist attacks of the past 15 years have resulted in the continuing requirement for pilots to undergo security screenings, further reducing the appearance that they were special in the eyes of the traveling public. In fact, these days, flight crewmembers are occasionally rebuked by passengers for cutting ahead of security screening lines. Such passengers have even been heard to complain that crewmembers should not receive preferential treatment.

Captains approaching retirement or those who have retired often reminisce about the esteem that they were afforded and about how the few disagreements that occurred in the bygone era were handled, back in the days when "the captain was king." Any disagreements with ground personnel or flight attendants were dealt with quickly and efficiently, often quite harshly. In many cultures, such respect (or fear) for captain's authority persists to some degree while in others, it is perceived as quickly receding into the annals of history.

Regulations are in place to protect captain's authority. In the United States, Federal Aviation Regulation (FAR) 91.3 (a) states that "the pilotin-command (PIC) of an aircraft is directly responsible for, and is the final authority to, the operation of that aircraft." 14 CFR 121.535 (d) states that each PIC is, during flight operations, "in command of the aircraft and crew and is responsible for the safety of the passengers, crewmembers, cargo, and airplane." FAR 121.557 allows the PIC to take any action considered necessary during emergency situations that require immediate decisions. 14 CFR 91, 125, and 135, all have similar language empowering captains with command authority. Challenges to captain's authority must be met head on, but with respect and politely. The authority provided to leaders must be used with great judgment by soliciting participation from subordinates. Leaders must also remember to never assume malice as someone's motivation for challenging authority when simple ignorance may be involved.

ASSERTIVENESS. Continuing with our discussion of the central theme of CRM, let us turn our attention to looking at the second component: assertiveness with

respect. Assertiveness is defined as “a style of communication in which individuals express their feelings and needs directly” (VandenBos, 2007). In CRM, assertiveness means that a crewmember should know what questions to ask and not be hesitant to ask them. Assertiveness also requires that crewmembers candidly state opinions about a course of action or planning item and voice concerns immediately. A five-step assertiveness process is often taught to subordinates in order to encourage the captain to act on the crewmember’s input. The advocacy of an opinion or of a desired course of action is imperative in the decision-making process, particularly in the highly time-sensitive environment of aviation (Kern, 2001).

A climate of mutual respect is the key to the success of interpersonal relationships in life and to completing tasks in any working environment. Given that professional pilots are, by virtue of their office, the end-result of many years of training, that notion alone should warrant a certain level of respect. However in CRM, the reasons for exhibiting respect when interacting with fellow crewmembers are not only an appropriate deference to one’s commitment to aviation, it also has direct ramifications for safety. It is only by respecting the input of a crewmember that one can expect future input to be provided. For example, a pilot who dismisses the concern of a flight attendant because it seems unfounded may not only be disregarding a key piece of information that affects the flight, but by virtue of the dismissal, may also have made the flight attendant reluctant to voice concerns in the future. Likewise, a crewmember who shows disrespect toward a person in a position of authority can also negatively impact the CRM process by making the senior member more hesitant to solicit input.

Proof of CRM Effectiveness

Although CRM has evolved through numerous stages since its inception, the basic premise is the notion that very often someone in the sequence of events has the power to intervene and prevent an accident. The external and internal factors that prevent key individuals from taking action to prevent an accident have been the subject of countless studies.

We now have a better understanding of some of the key issues that form part of what the aviation industry calls CRM. However, we would be remiss if we did not ask the most fundamental of all questions: does CRM really work? Some questions can only be answered with time. Now that the CRM movement has several successful decades behind it, data can be depicted showing the tangible impact that CRM training has had on the safety of aviation.

In most airlines of the Western world today, CRM skill sets are a core

component of initial and recurrent training curricula. Nevertheless, pilots and the personnel who support them continue to make significant human errors that make it very challenging to further reduce the rate at which accidents happen. It should be noted that no one has proposed that CRM is a means for eliminating *all* errors. CRM is a way to address error, but do we have proof that CRM actually *has* increased the level of safety with which we operate aircraft? From the very beginning of the CRM movement, flight training instructors, curriculum designers, and aviation researchers have sought to find out whether the methodologies they were designing actually were producing a benefit. The desire to quantify whether error management methodologies are effective predate the CRM movement. Such efforts emerged out of general research in the field of psychology and out of customized studies in aviation human factors. As illustrated in Figure 4-3, NASA has used human test subjects who are often active airline pilots for simulator studies about CRM. Additional literature materials and citations regarding CRM theory and practice can be found in the online supplement to this chapter.

FIGURE 4-3 Simulation studying CRM and use of advanced technology. (*Source: NASA*)

CRM PYRAMID MODEL

Given the many components of CRM and the various ways that each component affects each other, it proves convenient to produce a model of how everything works together. The reader may recall the discussion in Chapter 2 of why such models are helpful. As concepts become increasingly complex it is common to resort to models as a way of helping to understand how the concepts interrelate. They help us grasp “the big picture” so we can try to make sense of it all. Also remember the previously mentioned caveat that since models are inherently attempts to simplify, they can sacrifice knowledge of the nuances that are sometimes critical to getting the full picture of all the types of factors involved in an accident.

Bearing in mind such limitations of conceptual modeling, a depiction called the CRM Pyramid model, shown as Figure 4-4, has been created to help the reader interpret and contextualize the contents that are to follow about CRM. The model is in pyramid form as a way to facilitate understanding and illustrate how certain components of CRM are fundamental building blocks, or prerequisites, for subsequent models.

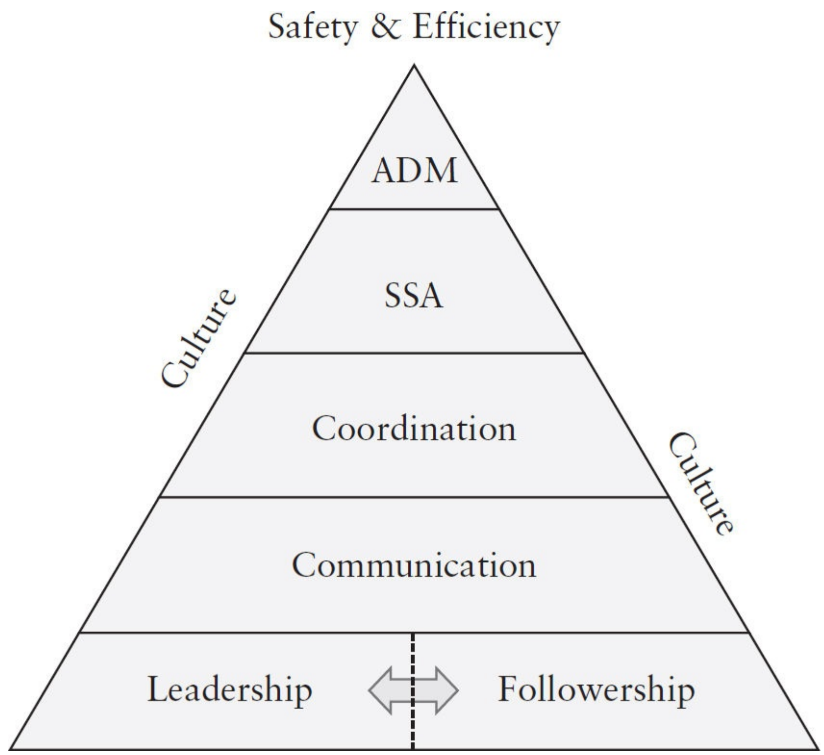

FIGURE 4-4 The CRM Pyramid model. (*Source: Authors*)

Let us read the pyramid model from the top-down. Hovering above the model are the two reasons why CRM is such an important part of commercial aviation. When properly performed CRM directly leads to the creation and sustainment of safety and efficiency. The terms safety and efficiency are intimately related, in that an accident is the ultimate expression of an inefficient system. Grouping both terms together is also meant to imply that the processes that promote safety can also promote the efficiency of aircraft operation.

So, going back to the model, notice that both safety and efficiency are the direct products of *Aeronautical Decision Making (ADM)*, which is the top-most component of the pyramid. ADM refers to how pilots use mental processes to consistently determine how best to respond to a given set of circumstances. ADM is only as good as the *Shared Situational Awareness (SSA)* of the team members who are involved in making the decision. SSA refers to the common

perceptions and comprehension of an environment and how they impact the future, as held by two or more people. The accuracy of SSA creates the reality and the common mental model of the team members, and therefore, directs their decision making. The SSA is a product of how well a team coordinates its actions, which depends intimately on the verbal and nonverbal communication of members, which explains why the *coordination* component underlies SSA and why the *communication* component underlies coordination in the model.

The foundation of the model is *leadership and followership*, since the effectiveness of the interplay between leaders and followers directly impacts the quality of communication that is used to coordinate actions that build SSA for peak ADM. That is how the CRM Pyramid model works to depict the interrelation of the key components of CRM. Affecting every component of the model is *culture*, which means the shared values and beliefs of a group of people, often impacted by behavioral norms shaped by a nation, profession, and organization.

Although the CRM Pyramid model was just described from top to bottom, the ideal way to study each component is to start with the foundation, leadership, and followership, since the interplay of both set the stage for everything that follows inside of the pyramid, except for culture. The next parts of the chapter cover each component of the model and finish the chapter by describing how culture impacts the overall conduct of CRM.

LEADERSHIP AND FOLLOWERSHIP FOR SAFETY

Leadership can be explained in many ways. In the context of safety, leadership can be defined as “the process by which an individual influences the behavior and attitudes of others toward a common goal.” The role of such influence in commercial aviation has a direct bearing on the safety of an operation, but is not always addressed when discussing accident prevention. Followership is as important as leadership and describes the ability to take direction well and to deliver on what is expected of someone by a leader.

The cumulative effect of such influences, when taken across the entire employee group, fosters a certain safety culture that sets the expectations for behaviors and attitudes about risk. There are many leaders in commercial aviation, although we focus on the role of the captain given the direct impact that influence yielded by the captain has on the safety of a flight operation. This section commences by discussing the aspects of leadership that impact the CRM Pyramid model and then flows into the role of followership. Together, the working relationship between leaders and followers sets the tone for the other

working relationship between leaders and followers sets the tone for the other elements contained within the CRM Pyramid.

Let us start by addressing the common confusion over the difference between management and leadership. Management is the process of “planning, organizing, directing, and controlling” behavior so as to accomplish a given workload by dividing up tasks (Wagner & Hollenbeck, 2005). Most managerial tasks to be completed by flight crews are carefully described in each organization’s standard operating procedures (SOPs). Such a situation seems to diminish the necessary managerial actions of a captain but does not address the pressing need for leadership, which is about setting the example for others to follow and consists of designing a system of incentives and disincentives for encouraging the behavior of followers. Leadership revolves primarily around the concept of creating a positive work atmosphere so the crew effectively manages resources and complies with procedures (Lumpé, 2008).

Perhaps the best way to harmonize the differing opinions between “managing” and “leading” is to recognize that commercial aircraft captains must perform both managerial and leadership functions as part of their job and that both aspects have a direct impact on safety. Such a dual-charge can be described as necessitating an ability to “direct and coordinate the activities of other team members, assess team performance, assign tasks, develop team knowledge, skills, and abilities, motivate team members, plan and organize, and establish a positive atmosphere” (Northouse, 2007).

Ten Key Actions of Capable Safety Leaders

In many ways, the *pilotin-command (PIC)* of an aircraft is the chief executive officer (CEO) of the aircraft. Just as a CEO is responsible for the well-being of employees, satisfaction of customers, financial health of a company, and ethical decision making, so too is the PIC (or senior aviation manager) responsible for all that happens when he or she is in command.

The following section contains a list of what the authors believe are the top 10 key actions exhibited by capable aviation safety leaders. Although adjustments may have to be made to any list of actions by capable leaders in order to deal with particular circumstances, the list is a useful guide for key actions for all aviation professionals.

1. *Set the Stage for Safety Excellence*. An effective leader can commence the process of team-building by explaining the challenges that will likely be faced and by depicting how open communication and shared input into the

decision-making process can overcome those obstacles.

2. *Encourage Participation in Authority to Promote Safety*. Leaders use the authority that has been given them to influence mission accomplishment while simultaneously encouraging participation. They welcome comments from team members who take pride in mission accomplishment.

3. *Strive to Create New Safety Leaders*. The training that a leader receives in preparation for upgrade should not just consist of technical aspects of troubleshooting and decision making, but of the leadership aspects as well. Leaders must be able to encourage the development of leadership in their subordinates.

4. *Lead by Example to Show Sincere Care for Safety*. Leading by example means that leaders should be enthusiastic champions of the mission and should try to motivate their crew to excel in meeting the mission objectives. It also means that those in charge should readily acknowledge their mistakes instead of constantly working to protect personal image or ego. True students of leadership will view unpleasant situations faced by their crewmembers as excellent learning opportunities to lead by example.

5. *Active Listening*. A key means for promoting communication is developing active listening skills. Knowing when and what to communicate means knowing when to listen versus when to speak. It also means actively listening to what others are saying while consciously attempting not to filter or block the message that is being broadcast.

6. *Manage Resources and Performance*. Another key aspect of leadership is knowing how to distribute and manage workload effectively. The leader must step in to establish what tasks should be done, when the work should be accomplished, who will perform the tasks, and the expectations for completion. The previous chapter explained the intimate relationship between workload and situational awareness.

7. *Take Care of Followers*. Leaders take care of those employees under their care. The captain or senior aviation manager should make an effort to consider the special needs and circumstances of each team member. Sincerely caring about subordinates' well-being sends a strong message about mutual accountability and furthers the leader's attempt to build and maintain teamwork.

8. *Constantly Work on Building the Team*. It is important to make each crewmember feel valued. When major decisions are to be made, the leader should solicit and respect input from everyone.

9. *Delegate Authority but Never Responsibility*. The leader must delegate sufficient authority to members of the crew to perform different tasks while always retaining responsibility for the proper accomplishment of such tasks. It is impossible for a single individual to accomplish all the tasks required in complex aviation operations.
10. *Be Ethically Courageous*. Numerous situations are presented on every flight for a captain's ethical courage to be tested. All too often it is more comfortable to simply allow an untrue statement or unsafe condition to fade into the recesses of memory instead of taking action to prevent a recurrence of the condition in the future.

The traits and actions of effective leaders can certainly be discussed but must always be molded to fit the context of a situation. What is an aviation professional to do then in order to become a capable leader? The answer lies in the pursuit of excellence by developing one's personal leadership style. After all, how can one be an authentic leader by trying to emulate someone else? We can certainly learn lessons from other leaders and apply behaviors that we believe are successful, but ultimately we must create our own authentic leadership style. The 10 safety leadership actions portrayed here thus form the core knowledge base for developing one's own style through experience, reflection, and continued study.

FIVE KEY ACTIONS OF EFFECTIVE SAFETY FOLLOWERS

At this point we must acknowledge that not all subordinates are destined to become leaders. Take the following example into consideration. Some first officers in seniority-based management systems are happy with having accrued sufficient seniority to bid excellent schedules while not being weighed down with the burden of command. Such pilots may spend most of their careers with little ambition to upgrade to the captain's left seat. That having been said, the first officer or other subordinate should be cognizant that he or she is also in a leadership position by virtue of exercising authority when it is delegated. For example, the captain (or other senior aviation manager as appropriate) will delegate the authority of the flight to the first officer while the captain is away from the flight deck. Some argue that listing followership actions separate from leadership actions is unnecessary, since both lists contain similar items. Although such an assertion is certainly true to an extent, there is value in describing the specific actions that seem more germane to followership than to leadership. Most leaders would agree that the items provided below are the key

actions of aviation safety followers.

1. *Exhibit Assertiveness with Respect*. Regardless of what tone has been set by the leader, team members have an ethical obligation to be assertive and to voice concerns and opinions on matters of importance to the safety in aviation. To act assertively is to be honest, direct, and self-confident while respecting others. Workers who are assertive in a disrespectful manner may be tuned-out by leaders and labeled as "trouble makers" who have nothing to contribute.
2. *Adopt a Sense of Ownership*. It is a professional obligation for employees to act as if they are actual owners of the aircraft being operated and safety representatives of the company that provides employment. Such a responsibility is a matter of pride and comes from the realization that each of our actions impacts the bottom-line of an operation.
3. *Strive for Self-Improvement*. One of the key obligations of being a professional is striving for self-improvement. As soon as we settle for "good enough," we psychologically start sliding backwards and our work performance soon follows. Always remember that *good* is the enemy of *great*, as the expression goes.
4. *Show Respect for Fellow Crewmembers*. Showing respect to the other members of the crew is not just a matter of courtesy, it is fundamental to fostering a sense of shared purpose that is the building block for teamwork. This means actively listening for content in what another crewmember is saying, not just "hearing" what is being said.
5. *Always Be Dependable*. A follower has a key obligation to always be dependable. Employers and leaders need to be able to count on people to fulfill their professional responsibilities and also to complete any tasks that they agree to perform.

TRANSCOCKPIT AUTHORITY GRADIENT (TAG)

The captain's ability to promote assertive behavior in other crewmembers is directly impacted by the *perceived* authority gradient that lies between the captain and subordinates. Personal factors such as one's designated crew position, age, experience, proficiency, confidence, gender, depth of voice, reputation, physical size, assertiveness, and similar qualities may help create a perception of which pilot exudes more *informal* authority in the cockpit. A distinction here is drawn between the formal authority given to a leader and the

informal authority that can be present in any team dynamic.

Ideally, a captain will be perceived as having more authority than anyone else in the cockpit. However, a captain who creates the perception of exuding too much or too little authority is a formula for possible CRM problems. It is the captain's job to know how his or her authority may be perceived by others, to be mindful of the perceived gradient between the captain and other crewmembers, and to take measures to adjust the gradient for optimal communication flow. Because such gradients usually exist between the crewmembers of a given cockpit, the term Transcockpit Authority Gradient (TAG) is used to describe this dynamics.

Figure 4-5 depicts the four types of TAG that can be present. The left side portrays TAG-1, which has a gradient too steep for proper authority to be delegated while still being able to keep two-way communication channels open. Such an overly steep positive TAG may develop when a captain is perceived as being a domineering type or when a subordinate lacks confidence or assertiveness. An example of when such a TAG may occur is when an instructor or examiner pilot is paired with a relatively new pilot. Moving to the right in Figure 4-5, TAG-2 shows a flat authority gradient where there is equal or nearly equal perceived authority among both pilots or between two crewmembers. Such a level-playing field sounds quite pleasant but can actually be very dangerous because it may lead to role confusion. Such a situation may exist when two very experienced pilots are paired for a flight, or when two inexperienced pilots are paired with each other.

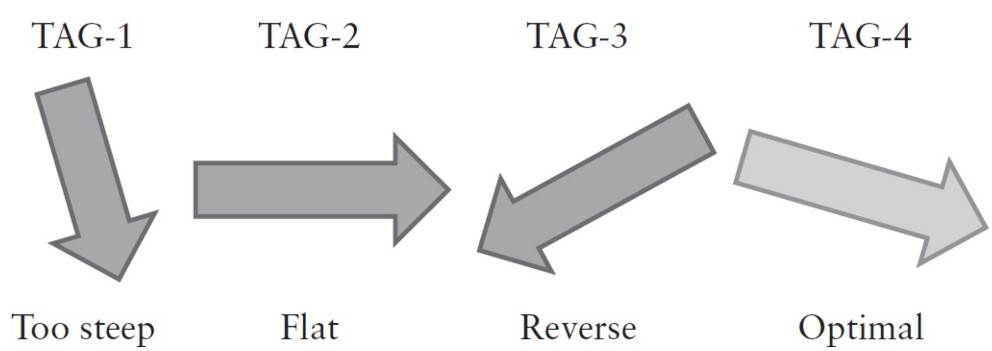

FIGURE 4-5 Four types of TAGs. (*Source: Authors*)

Moving one more depiction to the right in Figure 4-5 shows TAG-3, which is a very dangerous reverse TAG, meaning that the subordinate has more effective authority than the designated leader. It occurs when the captain is still the designated leader but is no longer the functional leader of a crew. When a negative TAG is present, another crewmember exerts too much influence on the

decisions that are being made. Negative TAGs create very dangerous situations since the individual who is vested with official authority, as recognized by regulations and the operating organization, ceases to be the individual who is exerting authority. An example of such a TAG is when a new first officer happens to be highly experienced in a certain emergency procedure or a specific airfield and the captain starts deferring to the first officer's direction for dealing with the emergency or location. Negative TAGs have led to several notorious accidents, such as the runway collision between a DC-9 and Boeing 727 at Detroit in 1990. Thus, it is a safety concern for aircrew dynamics and aviation professionals to consider.

The best authority gradient, where the captain is recognized by all as the decision maker of the crew, but where subordinates feel invited to participate in the decision-making process, is depicted in the light shade of gray by TAG-4 in Figure 4-5.

It is a professional responsibility of all crewmembers to be aware of the TAG and to attempt to manage the TAG. If a captain notices an overly assertive first officer who starts making decisions about the flight unilaterally, action should be taken to reestablish the TAG. Sometimes all that is required to flip a negative TAG back to a positive slope is a gentle reminder by the captain to the crewmember that input is invited, but the decision rests with the captain. Likewise, subordinates must be mindful that their level of confidence and assertiveness should not take away from the captain's need to make decisions.

COMMUNICATING FOR SAFETY

Effective communication is one of the key features and outputs of properly performed leadership and followership. Although we tend to think of communication mostly in terms of verbal exchanges, other types include the use of writing, nonlinguistic symbols, gestures, and implied understanding of the actions of others. All such types have numerous pitfalls, but our heavy reliance on verbal communication has made for ingenious developments to attempt to make communication more accurate. This section contains some of the many initiatives that have been developed. Figure 4-6 shows air traffic controllers communicating with each other verbally, through written means, and through the use of symbols, plus also speaking with aircraft flight crewmembers and others operating on the airport ramp, such as tug drivers towing aircraft and drivers of airfield vehicles such as fire trucks and wildlife control officials.

FIGURE 4-6 Air traffic control tower personnel. (*Source: Wikimedia Commons*)

One of the most known communication techniques for fostering accurate communications evident to those listening in on the aviation industry is the use of the phonetic alphabet to ensure the proper spelling of different terms, such as navigation aids, waypoints, and taxiways. Because spoken sounds can be difficult to discriminate, especially over crackling or congested radio frequencies, British Army signalers commenced using a version of today's phonetic alphabet in the late 19th century. The system has evolved over the years into the system of codes known today, where "A" is phonetically pronounced as "Alpha," "B" as "Bravo," *etc.* There is still the potential for error in some cases, such as the "Delta" used for the letter "D" given that Delta is also the name of a popular global airline.

Most of the world has adopted the use of the 24-hour clock to prevent confusion with the same hours occurring twice a day. Unlike society in the

United States and a few other countries where the 12-hour clock prevails and in which am/pm distinctions must be made to clarify whether someone is referring to 8 o'clock in the morning or 8 o'clock in the evening, the 24-hour clock removes the confusion immediately. The 24-hour clock is the international standard put forth by ISO 8601 for the exchange of time-related data and is the mainstay of aviation. As such, 8 am becomes 08:00 or 08'00 hours and 4 pm becomes 16:00 or 16'00 hours. Furthermore, aviation has adopted the use of Coordinated Universal Time, abbreviated as UTC, as the primary time standard for regulating clocks and time. (This is nearly synonymous with Greenwich Mean Time or GMT.) The 24-hour time standard tied to UTC is an attempt to have a single reference time across all time zones on our planet. When referencing such time it is common for aviation personnel to use the term "Zulu" and to differentiate it from "local" time to prevent confusion. For example, a pilot in China speaking with his dispatcher in Paris would refer to "sixteen hundred Zulu" to indicate 4 pm Coordinated Universal Time, so that both the pilot and dispatcher would know precisely what time they are referring to when speaking. Such a means for accurate coordination proves critical not just for discussing takeoff and landing times, but also for reading meteorological observation and forecasts and countless other issues in aviation.

Given the vast number of terms used in aviation, emphasis is placed on the use of pre-approved and coordinated standardized phraseology for referring to different items. The *U.S. Aeronautical Information Manual* has a 118-page long glossary of pilot/controller terms precisely for that purpose, although many other uses of standardized phraseology may apply within different companies and even between aircraft makes and models. For example, "TOGA" to a pilot often means "Take Off/Go Around" in reference to a power setting used for certain aircraft operations.

Since the English language is the international standard for aviation, certain traps must be discussed that come along with the language and which can be detrimental to safety. In English the words "to" and "too" and the word "for" and "fore" are used in common speech but unfortunately also sound like the numbers "two" and "four," respectively. Some aviation professionals have intentionally removed those nonnumerical words from their speech while at work to reduce confusion with numbers. Thus, instead of a pilot saying, "Leaving one three thousand feet for eight thousand feet" they will replace the word "for" with "descending" and read the same sentence.

One of the authors of this book remembers a very confusing exchange when a flight whose weight required the suffix "heavy" to the callsign and which had a number "two" as the last digit of the callsign. The flight's callsign was "452

Heavy." The flight checked in with an en route traffic control center as "Four Five Two Heavy" at an altitude but was interpreted by the controller as being "Four Five too heavy" and therefore the controller thought the flight was too heavy to sustain flight at the altitude. Using the fictitious callsign "Skid 452" as an example, this is how the check-in sounded to the controller: "Denver Center, Skid Four Five Two Heavy Flight Level 350." The controller heard the callsign as "Skid four five" and then misheard "too heavy" for the given flight level, so then quickly issued a lower altitude. The Skid flight descended and later queried the controller as to the descent. When the controller answer that the flight had requested the descent and the flight crew responded, "No we didn't," the situation started getting almost comical. The confusion was finally noticed by the controller who apologized and reissued the previous altitude.

One important concept that should be grasped by all aviation professionals to ensure safe operations is the need to close communication loops. The concept entails the notion that a message originates with a sender, is then received and interpreted by, hopefully, the intended recipient, and then the recipient follows up to ensure that the message was appropriately interpreted (Salas, Rosen, Burke, & Goodwin, 2009). The concept forms the cornerstone of the "readback" process used to confirm air traffic control clearances but can be used any other time that it is critical to ensure that information has been correctly communicated. For example, when a maintenance controller communicates over radio the steps required to remedy a landing gear malfunction to an aircraft pilot, it proves wise for the pilot to read back the instructions over the radio prior to commencing the remedial action on the flight deck.

Given our tendency to not use more words when communicating than necessary, particularly when busy or tired, the limiting of information exchanged can actually hamper the communication process. For example, one of the most confusing expressions in aviation is, "I got it." The phrase is extremely ambiguous and has caused countless misunderstandings. Given that the phrase's meaning can include that something is understood, that a physical object is in one's possession, that something is sighted, or countless other meanings, it is easy to see the source of confusion.

Imagine the following exchange on a flight deck, which is not farfetched at all, to illustrate the potential for confusion. A captain is speaking with a jumpseat passenger about the new month's duty schedule while the first officer is monitoring the air traffic control frequency. At the same time that the jumpseat passenger asks the captain if he has a copy of next month's duty schedule, the air traffic controller issues a traffic call to the first officer regarding

a light aircraft. The first officer then strains her eyes in the direction of the traffic to see if visual contact can be established, but at precisely that same moment the captain answers the jumpseat passenger's question with, "I got it," referring to the duty schedule, and the first officer assumes the captain has the traffic in sight and responds accordingly to the air traffic controller. Moments later, the traffic zooms by a few hundred feet above the flight deck and shocks the first officer, who turns to the captain and states, "I thought you had the traffic in sight!" The captain then answers, "What traffic?"

Although this section has focused on initiatives used to ensure verbal communication accuracy for safety, numerous other approaches are taken to promote the same in nonverbal communication. For example, some aviation personnel underline the letter "S" when used as part of an alphanumeric sequence in order to prevent confusion with the number "5." For example, A<u>S</u>5TH685<u>S</u>. Without the underlined numbers, there is significant potential to misinterpret the alphanumeric notation, especially if it is handwritten by someone else. Similarly, some professionals chose to slash zeros to differentiate them from the letter "O" and slash sevens to differentiate them from the number "1," all to prevent confusions in alphanumeric writing. Also, extensive use of hand signals can occur between ramp personnel and flight deck crewmembers to communicate different actions when not using headsets for verbal communication, such as for connecting external ground power and removing wheel chocks. Such hand signals must be standardized, taught, and enforced in order to ensure clear communications safety.

COORDINATING FOR SAFETY

Closely related to the concept of communication is coordinating actions that promote safe and efficient commercial flight operations. As part of the CRM Pyramid model, when proper leadership and followership principles are followed and efficient communication is employed, coordination of actions can then lead to shared awareness of a situation and subsequently produce good decisions. Coordination, in this context, means carefully organizing who performs what actions in a complex activity to accomplish tasks.

Curiously, researchers who have studied high-performance teams in action have determined that they can often coordinate their actions without the need to communicate in real time because of well-timed and planned previous communication (Cannon-Bowers & Salas, 2001). Such planned previous communication usually entails briefings, aircraft and automation control,

standard callouts, and protocols for working with cabin and external team members. This section focuses on the use of briefings as a key tool for building shared awareness of a situation and features some of the most common briefings that are used in commercial aviation.

Whether it is a lead ramp agent briefing a push-back crew before a nonstandard operation or a captain briefing fellow flight deck crewmembers on an approach as is shown in Figure 4-7, briefings are one of the most successful means of coordinating actions and fostering a common mental picture of a situation. As a minimum, every good briefing must have four major components (Zohar & Luria, 2003):

FIGURE 4-7 Captain briefing first officer prior to landing. (*Source: Wikimedia Commons*)

1. Creating a big picture of what is going on
2. Explaining what we want to accomplish
3. Directing the small picture of who will do what
4. Exploring contingencies through *if-then* problem scenarios

Given the complexity of some briefings, many crewmembers rely on written

Given the complexity of some briefings, many crewmembers rely on written notecards containing briefing items to ensure that key points are covered. One of the most important flight crew briefings that takes place is the before-flight briefing for the entire crew, including flight attendants, which is sometimes called the “CRM briefing.” This briefing is performed by the captain after reviewing preflight planning information and receiving a dispatcher briefing and takes place as early as possible before crewmembers commence their onboard duties. One of the primary purposes of the briefing is setting the tone for the collaborative spirit of the crew.

There is an old saying in aviation that warns of consequences for those captains who skip this briefing: “By not setting the tone, you have set the tone.” That is why this key event is sometimes called the “CRM briefing.” It takes place at the start of every day or every new crew pairing and can be accomplished at different times prior to commencing checklists. It should be briefed by the captain and should strive to accomplish all items that are general to the flight or series of flights that the crew is paired to fly. Some important items in the *CRM briefing* may include the following:

- General introduction of crewmembers (experience level? currency?) to include meeting the flight attendants, the presence of air marshals, other armed personnel, and jumpseat passengers (often off-duty pilots or flight attendants)
- The openness of the captain to input and the importance of keeping lines of communication open between the cabin and the flight deck
- Any mechanical faults present in the aircraft that may affect passengers or cabin operations
- Weather conditions that could impact normal operations and passenger service, such as turbulence or destination fog that could necessitate holding or a diversion to an alternate airport
- Expected passenger loads
- En route flight times
- Providing everyone the opportunity to ask questions or make comments

The captain may brief other pilots on the flight deck of additional items that do not have particular relevance to cabin crewmembers, such as which pilot will control the aircraft on each leg of the trip (which usually implies that the other pilot will operate the radios), emergency procedures such as who will do what during a rejected takeoff, the expected fuel load, pertinent Notices to Airmen (NOTAMs), mechanical issues with the aircraft that affect flight deck

(NOTAMs), mechanical issues with the aircraft that affect flight deck operations, and weather information such as the expected need to de-ice and/or anti-ice the aircraft.

Other standard coordination through briefings include a *takeoff briefing* between the pilots, the flight attendants' *passenger preflight briefing*, and the *approach briefing* between the pilots. Nonstandard briefings may include the pilot communicating key information to the lead flight attendant during an emergency to include whether to expect an evacuation after landing and how much time is available to prepare the cabin for a landing during an airborne emergency.

An example of a nonstandard briefing is the *flight attendant emergency briefing*, which often contains five items. The briefing provides an outline from which to build the flight attendants' SA when there is a serious problem onboard. Once there is a need to explain the emergency plan to the flight attendants, the flight crew should follow the steps and give the briefing in its entirety. If the briefing is completed, the need for extensive further communication between the pilots and the flight attendant will be minimized, which will be a great help given the very high workload that takes place in both the flight deck and the cabin when dealing with inflight emergencies. This will help in many ways. If the attendants have questions that need to be answered due to a weak briefing, the pilots may be continually interrupted during a time of very high workload. This will only cause more time to be wasted, leading to reduced pilot SA, and will keep the pilots away from what they need to be doing. The advice given to captains about this briefing is typically, "give it once; give it well!" Ideally, the captain should be the one performing the briefing, and the lead flight attendant should be the one receiving it. The briefing will usually take place over the intraplane (cockpit-cabin) phone system. The flight attendant emergency briefing has five major steps which encompass all of the major areas that need to be covered:

- Definition of the problem
- Amount of time available until landing
- Whether to have the passengers brace for landing
- Whether an evacuation is expected after landing
- Any additional instructions, such as which exits should be used during an evacuation

The five-point briefing could turn into a lengthy speech; however, this must be avoided. Every aspect of the briefing must be ready prior to giving it to the

FA in a quick and clear manner. This will help the items to be easily understood and minimize the possibility of miscommunication. With this done correctly, the flight crew will be free to complete other subsequent tasks with the knowledge that the cabin crew knows what will happen. As when declaring an emergency to air traffic control, pilots should take a moment to query the flight attendant and ensure that he or she is ready to receive the briefing before proceeding with the briefing. This will be a high-stress moment for the flight attendant, who may be under a lot of stress already from normal cabin duties. An example for the entire briefing is provided below. It assumes that the captain is calling the lead flight attendant, named Jim, on the intraplane phone.

> *Jim, this is the captain. We are going to perform an emergency landing due to the passenger with the chest pains that you told me about. Are you ready for my emergency briefing? O.K. then, the problem is the passenger with the chest pain, you have about 15 minutes before we are on the ground in Topeka. The time is now 9:00 local exactly. Is that what your watch shows? There is no need to brace the passengers and everyone will stay seated until we taxi to the gate. Once at the gate, the emergency medical crew will board through the forward entry door and proceed to the ill passenger while everyone stays seated. I will make an announcement to the passengers over the PA in about five minutes. Do you have any questions? Please roger and repeat the briefing back to me.*

It will then be up to the lead flight attendant to ensure the other members of the cabin crew know the plan and to provide an update to the passengers so they too know what is happening.

SHARED SITUATIONAL AWARENESS (SSA)

The concept of SSA is tricky, in part because *fully* sharing awareness is not possible. If we consider SSA as several people having the same mental model of something that is happening or will happen, there is no way to achieve such a state with any degree of accuracy because we cannot read minds. However, this section highlights some of the clever means that humans have devised for working toward SSA, knowing that a significantly high level of SSA is usually sufficient to produce solid ADM in the context of flight operations. As explained by Klimoski and Mohammed in 1994, the numerous mental models that coexist among different members of a given team need not be the same but should have sufficient overlap to make it possible to perform a given task.

There are many names for the concept of SSA, such as team cognition, shared understanding, and distributed mental model, but essentially all terms describe knowing the factors that impact you and those around you and knowing whether those around you know so that you can actively work to build a common mental model of what is happening and about to happen.

Although a few definitions of SSA exist, the one best suited for this book is "the shared perception of factors that affect a flight, the shared understanding of how those factors impact a flight, and the shared projection of future actions based on the shared understanding" (Millward, 2004). The true challenge is having all members of a team working toward SSA during an entire aviation operation. A commercial airline flight crew may consist of over a dozen people working together for a dozen hours. It can prove very challenging to think about each other and be cognizant of the need to share information with each other so that SSA is retained over that much time.

As explained by Cannon-Bowers and Salas in 1998, SSA "allows team members to predict the needs of the task and anticipate the actions of other team members in order to adjust their behavior accordingly. In other words, team members appear to form expectations of what is likely to happen" (p. 28). SSA will constantly change as the individual SA of each team member changes and as different communication is performed to coordination activities. At any given moment among a group of people, each individual will have their own SA that is a dynamic picture of the situation in their minds and which has a direct impact on the overall SSA of the team. As the SA of one team member drifts away in terms of accuracy, it can cause the entire SSA to shift.

In addition to individual levels of SA, other factors that foster SSA include shared training experiences, pre-event briefings, post-event debriefings, strong verbal communication skills, standardized phraseology, predetermined roles for high-workload moments, and physical proximity to pick up visual cues that aid communication (Zohar & Luria, 2003).

When pilots and flight attendants *train together* by running through a cabin evacuation in a full-scale cabin mockup, they learn to see situations through the eyes of each other, and thus, understand their concerns and possible thoughts about a given task.

Post-event debriefings, such as when air traffic controllers analyze a loss-of-separation event, can greatly build future SSA in a way similar to training together, by learning the considerations that were present in the mind of a colleague during an event. The many briefings used in commercial flight operations, such as between dispatchers and flight crews, pilots and flight attendants, and flight attendants and passengers, build SSA quickly by communicating the status of different items and the actions that may have to take place during both normal and emergency situations.

In similar fashion, having *predetermined crew roles* during high-workload moments sets basic expectations of behavior. For example, each crewmember is

taught very specific actions to accomplish during a rapid decompression of an aircraft cabin. During such an event there is just not enough time to communicate and coordinate the required actions to build SSA, so the SSA is built beforehand through predetermined responsibilities. Those responsibilities are often contained in standard operating procedures as previously noted. A good example of how factors impact SSA that most can relate to is the distraction of speaking on a cell phone while driving. A reason why speaking on cell phones while driving a car is more dangerous than speaking with someone riding in a car is because the driver has less SSA with the caller than with the rider.

For example, the caller will not know that the driver is performing a tricky merge onto thick traffic on the highway and may chose that precise moment to ask a question such as, "Did you think the proposal we pitched at the presentation was properly supported with examples?" While a rider in the same car with SSA may wisely chose to wait until the car has properly integrated into the traffic flow before asking the question. That is one reason why having "hands free" cell phone capabilities in cars does not fully reduce the element of distraction and is not the same as simply speaking with someone in a car.

One of the most important concepts to learn is that the possibility to enhance SSA exists whenever someone knows something that other crewmembers don't, as long as the information is shared at the proper time with colleagues (Millward, 2004). That same year, Millward also produced a handy guide to building SSA via the *"STUFF"* acronym:

S—Share information without being asked and do so often
T—Try multiple communication strategies to ensure you are understood
U—Use a shared vocabulary
F—Frequently confirm the group goal and your role in achieving it
F—Forecast the needs and actions of others and adapt your behavior accordingly

Another key concept is that whenever confusion arises that shows that SSA may be damaged, team members should attempt to communicate along all three levels of the SA spectrum, namely, perception, understanding, and projection (Endsley, 2008).

For example, imagine an air traffic control supervisor who asks one of his tower controllers, "What is United doing?" That is a request to receive information about the actions of traffic to help build a common picture between two controllers. The other controller may answer, "He's almost there." You can see how such a communication exchange does very little to build SSA, in part

see how such a communication exchange does very little to build SSA, in part because the exchange is composed of highly ambiguous statements that could have many meanings. The supervisor may have been trying to ask why a United Boeing 737 was not on the standard taxiway leading up to a runway for departure, but the other controller may have thought the supervisor was asking about why a different United flight that was on another taxiway and holding short of the runway had not been cleared for takeoff yet and answered accordingly. As previously mentioned, to maximize SSA, the communication exchange could have occurred across all three levels of SA. Doing so may have produced the following exchange: the supervisor would have asked, “The United on taxiway Charlie (perception) is not on a standard route (understanding), where is he going (projection)?” The other controller would then know precisely how to answer the question so as to share awareness by saying, “He’s waiting to cross the active runway and taxiing to the hangar for maintenance.”

AERONAUTICAL DECISION MAKING (ADM)

The key products of CRM and TEM lead to ADM, which can be explained as a mental, systematic approach for determining the best solution to a given situation. Despite continuous improvements in technology for flight safety, the human factor that leads to errors still remains. Understanding ADM also explains how personal attitudes can affect decision making and how those attitudes can be adapted to improve safety in the flight deck.

As the CRM Pyramid model describes, the optimal environment for ADM starts with good leadership and followership that engenders effective and appropriate communication between seniors and subordinates. When this type of communication has been established, this leads to coordination between everyone involved, which produces SSA. This in turn leads to the environment which produces the best ADM. Additionally, culture greatly impacts the atmosphere for good ADM. It impacts how leaders and followers communicate and interact with each other. FAA Advisory Circular (AC) 60-22 explains ADM as a systematic mental process used by those involved in aviation to consistently determine the best course of action for a given situation.

THE IMPACT OF CULTURE

Over the past few decades there has been increased scrutiny of the role played by culture in teamwork. Culture has been defined as the “Shared values (what is important) and beliefs (how things work) that interact with an organization’s

structure and control systems to produce behavioral norms (the way we do things around here)" (Reason, 1998, p. 294).

Culture should be examined at a deep level to see how it can impact everyday commercial aviation operations. In addition to the influences of an employee's sense of culture on safety directly through perceptions of acceptable risk, we should also consider the impact that cross-cultural groups of employees have on safety when they interact with each other (Dong & Liu, 2010). When speaking of pilots and flight attendants, it has been determined that three cultures primarily impact their shared values: the *national culture* of each individual crewmember, the *professional culture* of each employee group, and the *organizational culture* at their place of work. Each of these three cultures impacts the safety of a flight both positively and negatively (Metscher, Smith, & Alghamdi, 2009).

National culture comprises the attitudes, behaviors, and values as a function of heritage (Helmreich, Merritt, & Wilhelm, 1999). National cultures create values associated with individualism versus collectivism, masculinity versus femininity, and power distance; all of which certainly affect the interplay between members of a team. The dimension of individualism versus collectivism within national culture imprints people with a level of concern for their own interest versus the collective interest of a society and sets the stage for how one sees themselves as a member of a team (Hofstede, Hofstede, & Minkov, 2010). The national culture dimension of masculinity versus femininity refers to attributes that are valued regarding traits traditionally associated with gender, where masculine societies are generally more assertive, competitive, and reward-oriented, whereas feminine societies have individuals who are generally more modest, caring, and cooperative (Strauch, 2010). *Power distance* is a cultural measure of hierarchical degrees in society, meaning how lower ranked individuals accept the power of those perceived to be above them (Hofstede et al., 2010).

Figure 4-8 shows a commercial airline flight crew operating an MD-82 for Zagros Airlines, which is an Iranian company founded in 2005. Think of the components of the CRM Pyramid model and of the different ways in which national culture impacts shared values, as explained in this section, then contemplate how the national culture of Iran, or that of any country, impacts how CRM is conducted.

FIGURE 4-8 Zagros Airlines MD-82 flight crew. (*Source: Wikimedia Commons*)

Each employee group is influenced by the culture of their profession. When we speak of a professional culture we refer to the traits and values common to a given profession that distinguish it from other employee groups. Just look at the different employee groups at any given organization, and aspects of their culture will start becoming evident. In commercial aviation the wings that pilots wear pinned on their uniforms pay homage to a rich heritage of adventure and technical prowess stemming back over a century. The piloting profession has long valued resolute decision making, technical know-how, education, and rigorous training as traits that set them apart from other employee groups, and pilots therefore have developed significant self-esteem and pride. Unfortunately for pilots, negative aspects can also be associated with these values, such as a false sense of invulnerability that worked against adopting the principles of CRM when they were introduced and which still make some feel impervious to the effects of fatigue, and refusals of assistance offered by other employee groups (Helmreich, Wilhelm, Klinect, & Merritt, 2001).

Organizational culture refers to the traits and values common to the members of one company, or airline in our case, that sets them apart from other airlines. Although other cultural differences, such as the ones described in this section,

certainly influence the values of members of an organization, each airline will also infuse beliefs, norms, and attitudes into its members (Wise, Hopkin, & Garland, 2010). For example, some airlines promote fun and low-cost travel as values that penetrate into the mindset of employee groups as evidenced by humorous ties, optional hat-wearing policies, leather jackets, and laid back attitudes, whereas other airlines are more formal, as evidenced by double-breasted uniform jackets, strict hat-wearing policies, and no-nonsense attitudes toward accomplishing tasks. Organizational culture impacts the safety performance of an airline by shaping how employees perceive the importance of risk detection and management (Hayward, 1997).

One critical expression of organizational culture is the common values held toward risk, known as safety culture. Safety culture became a hot topic among accident investigators in 1979 with the controlled flight into terrain in the State of Maine of a de Havilland Canada DHC-6 Twin Otter operating as Down East Airlines flight 46. In 1991 the NTSB started publicly showcasing the role of safety culture when it discussed the maintenance operations of an Embraer EMB 120 Brasilia operating as Continental Express flight 2574 that crashed in Texas following the sudden inflight loss of the left horizontal stabilizer's leading edge. Since that accident, there have been a steep increase in mentions of safety culture by airlines and investigators. Safety culture remains a key influence on all components of the CRM Pyramid model.

CASE STUDY: JETBLUE FLIGHT 292

An excellent example of how properly used CRM can produce a human victory in aviation was seen by the actions of an Airbus 320 flight crew, operating JetBlue Airlines Flight 292, in September 2005. The crew encountered an unsafe gear warning on a flight from Burbank, California to New York City.

When the captain raised the landing gear lever after takeoff, several error messages were displayed that indicated a problem with the nose-gear shock absorber or steering mechanism. The First Officer continued flying the aircraft in the vicinity while the Captain commenced troubleshooting. Given the indications that were noted, the flight manual cautioned that it was possible the condition indicated a nose gear that was cocked at a 90-degree angle to the fuselage. The nose gear of the aircraft was not visible from the flight deck, and no means existed to directly determine the angle of the nose gear from the flight deck.

Extensive troubleshooting and coordination ensued to determine the exact nature of the malfunction. It involved close coordination with a host of people

outside the aircraft, such as JetBlue maintenance controllers, dispatchers, and tower controllers. In addition to the required troubleshooting tasks, the crew also had to coordinate closely with the flight attendants and passengers; particularly given that some of the passengers were watching the event unfold via live television coverage on the JetBlue seatback entertainment systems. The crew decided to perform a low altitude flyby of the control tower at Long Beach to assess the status of their nose gear. As the flight descended and performed the flyby, JetBlue personnel at the Long Beach Airport went outside of their buildings to watch and even a local news helicopter took a peek at the gear's position. The tower controllers, JetBlue personnel, and the helicopter pilot all agreed that the nose gear was in fact cocked at a 90-degree angle. With the new information at hand, the crew decided to divert to Los Angeles and started discussing the implications of landing with a cocked nose gear.

Just prior to touchdown, the captain directed the flight attendants and passengers to brace. As the aircraft slowed to a stop, the tower controller called the captain and informed that no fire was visible. The captain then used that observation and contacted the cabin crew, advising that the passengers would be deplaned by using an airstairs instead of the emerging evacuation slides. Figure 4-9 shows the landing of the JetBlue flight 292 at Los Angeles International Airport with a cocked nose gear that created sparks as it was drug along the runway during the landing rollout.

FIGURE 4-9 The dramatic landing of JetBlue flight 292. (*Source: Wikimedia Commons*)

The pilots of Flight 292 must be commended for their methodical application of CRM to cope with a very undesirable situation. Although most air transport pilots would agree that a cocked nose gear is usually not catastrophic, a history of aviation accidents has proved on numerous occasions that seemingly minor malfunctions can result in major accidents when not properly handled by the crew. As can be seen in this example, effective aviation CRM is composed of a multitude of knowledge areas, ranging from communication processes and problem solving, to group dynamics and workload management. The accuracy of decisions made by pilots during routine flight conditions and during emergencies stems directly from the quality of the information that those decisions are based on. How a pilot goes about flying the aircraft while gathering and using useful information is the crux of what CRM is all about.

ASRS EXAMPLES

Following are two case study examples from NASA's Aviation Safety Reporting System (ASRS), in the original text submitted, including grammatical errors. The reader will see traces to the different components of individual human performance, professionalism, and the components of the CRM Pyramid model. Finally we will consider the case of a solid CRM positive example in the case of JetBlue Flight 292.

Ramp Operations: Example of Disregard for Authority

Title: Lack of regard for the authority of the captain by ramp personnel.

> *On gate and time for push back, the push crew said that they would take the brakes and hold the push awaiting for clrnc from ramp. There was an acft behind us so the wait was extended. Without prior coordination, the forward cargo door opened and bags were loaded. I asked the tug driver who had given clrnc for the pit to be opened. He said that we were just sitting there and he had told the rampers to throw the bags into the pit. I reminded him that the capt was the one who gave permission to open the doors after the brakes have been released. This opening the doors without coordination has become common with the rampers.*
>
> *The tug driver then stated that they could do this if we were waiting for clrnc. I then said, 'not without talking to the crew.' He then said, 'so write it up.' I then stated that he should read up on the procs. At this point we had been given permission to push and I informed the tug driver. He started the push by pumping the accelerator on the tug and bunching the tow bar against the nose gear several times. At least four times. I then directed him to stop the push, without a response at first. I had concern for the acft nose gear and for the flt attendants standing in the aisle doing their demos. Only after the second command to stop the push did the tug driver stop. Not wanting him to continue the bumping of the acft and realizing that he was mad at me, I directed a return to the gate and then directed for another push crew. We informed ramp of the problem and informed coordination ctl.*
>
> *The coordination ctlr was of no help in the sit and became very unprofessional and abusive to the crew insisting that the push crew was qualified to do the push and thus should be allowed to do it. She stated that we were being very unprofessional for keeping the pax waiting and that we should accept the push crew and go. The coordination ctlr made these statements without knowing what was going on. The ramp lead got on the headset and informed me that I had 'no right' to request another crew. I informed him that I had every right to protect the acft and the crew and that I would not accept an individual who takes his irritation out on the acft. He informed me that it would be five to ten minutes before they could get another crew, and I said fine. Soon after, the ramp supervisor arrived and had the jet bridge pulled back, and we discussed the sit. He said that he would look into the prob and requested a rpt be filed. I told him I would file the rpt and forward it to him. We pushed back with the new crew and departed.*
>
> *Ramp personnel opening the cargo doors without clrnc from the flt crew, tug drivers not using the proper terminology, or improper pushes have become a problem. Intentionally taking frustration out on an acft cannot be accepted.*

Discussion question for the reader: How can an airline encourage the concept of professionalism known as empowered accountability among employees who are paid minimum wage or close to minimum wage?

Flight Crew: Example of Steep Transcockpit Authority Gradient

Title: The captain's tone impacts the performance of others.

> *Have flown with this capt on 1 previous trip. He tends to be critical, thus on a subconscious level, I may not be offering him the backup that he needs. We were clred to hold as published at the gared intxn, l-hand turns. The capt has a bad habit of making pa's without warning me, which would give me a chance to put on my headset. Just as he begins a pa (rather than paying attn to flying or giving me the airplane) the acft enters a r-hand turn at the fix. I was looking at the flt plan to see how much holding fuel we had, I did not catch the error and as the acft flew away from the fix on the wrong side of the holding pattern, the ctlr gave us a vector. I queried the ctlr and she said it was because we entered the pattern incorrectly, at which time I immediately made the correction. A few seconds later the ctlr clred us direct to gared intxn to pick up the remainder of the korry 3 arr.*
>
> *Even though I emphasized to this capt that the pattern had l-hand turns, I did not catch the fact that he had it entered incorrectly in the first place. There is no excuse for me missing his turn, even though, his critical nature tends to make me stand off and not offer him as much. This I have realized after reflecting on this event. The same capt on the next leg criticized me in the presence of a chief plt on the jumpseat for briefing an obstacle, a large radio twr, on a visual apch. The list goes on. When treated like a second class citizen, perhaps my own performance became second class. Fatigue may have been a factor as well.*

Discussion question for the reader: The submitting pilot writes, "When treated like a second class citizen, perhaps my own performance became second class." What could the first officer have done differently to prevent this incident?

CONCLUSION

This chapter has explored the relationship of teamwork to safety and how teamwork in commercial aviation depends intimately on the commitment of each individual to being properly trained, experienced, proficient, and fit for the duties of his or her position. An airline sets the stage for these conditions to be met, but each individual employee must have the professionalism to do his or her part to ensure readiness to deal with both normal challenges and unexpected contingencies. Each employee should feel both empowered and accountable for the safety of a flight operation.

In order to extract the maximum benefit of teamwork for promoting safety, CRM has evolved through numerous stages of development to produce a central theme of encouraging participation in the authority provided to leaders and of promoting subordinate assertiveness with respect. The CRM Pyramid model provides insights into teamwork to learn how leadership and followership use communication and coordination techniques to share awareness of a situation so that optimal decisions can be made. Those decisions directly impact the safety of flight operations, and all components of the pyramid are under the influence of culture. Today, CRM and the related notion of Threat and Error Management

stand as best practices for team members working together to prevent accidents and maximize the efficiency of operating aircraft.

The takeaway of this chapter is that humans, when properly used in a team setting, can actually add more value to safety than they detract due to their innate tendencies to err as human beings. So now the reader knows the answer to the question posed earlier in the chapter: if we all make mistakes, then what is the advantage of having two pilots over one pilot on the flight deck of a commercial airliner? The advantage is that a team, when properly CRM trained and fit for duty, will catch many more errors than the combined sum that they produce, hence adding greatly to the safety value chain in commercial aviation safety.

KEY TERMS

“STUFF” Acronym
Advanced Qualification Program (AQP)
Aerobic Activity
Aeronautical Decision Making (ADM)
Approach Briefing
Assertiveness with Respect
Authority with Participation
Cockpit Resource Management
Communication
Controlled Flight into Terrain (CFIT)
Coordination
Crew Resource Management (CRM)
CRM Briefing
Culture
Empowered Accountability
False Expectancy
Fatigue
Fatigue Risk Management Systems (FRMS)
Flight Attendant Emergency Briefing
Influence
Just Culture
Leadership and Followership
Line-Oriented Flight Training (LOFT)
Liveware

Liveware
National Culture
Organizational Culture
Passenger PreFlight Briefing
Pilotin-Command (PIC)
Post-Event Debriefing
Power Distance
Predetermined Crew Roles
Professional Culture
Safety Culture
Shared Situational Awareness (SSA)
Takeoff Briefing
Threat and Error Management (TEM)

REVIEW QUESTIONS

1. In your own words, explain how professionalism impacts safety.

2. What are the major components of Crew Resource Management?

3. Do you think you can have strong Threat and Error Management without good Crew Resources Management? Why or why not?

4. Provide a personal definition of leadership and showcase a specific example of when your personal leadership was successful.

5. Choose a role model for the type of leadership that an aviation professional should exhibit. The person can be a real individual or a fictional character from a book or movie. Explain why he or she depicts the desired leadership traits to ensure safe flight operations as an aviation professional.

6. Explain the four types of Transcockpit Authority Gradients (TAGs).

7. Explain specific actions that a captain can take to reduce the effects of a steep positive authority gradient in order to promote assertive communication from the first officer.

8. Which follower action do you think is most critical for the aviation industry?

9. Would you prefer to be a leader or a follower in the aviation industry? Explain the reasons for your decision.

10. Take the Hazardous Attitude Inventory contained in Chapter 2 of FAA AC

60-22 and determine which are your most hazardous attitudes and potential antidotes for these attitudes.

11. Explain three examples of good CRM exposed in the JetBlue 292 Case Study.

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Pilot/Controller Glossary: http://www.faa.gov/air_traffic/publications/media/pcg_4-03-14.pdf

CHAPTER FIVE

THE ROLE OF GOVERNMENT

LEARNING OBJECTIVES

After completing this chapter, you should be able to

- Recognize the organizational structure of ICAO, the FAA, OSHA, and the EPA.
- Understand the basic rulemaking process of ICAO, the FAA, OSHA, and the EPA.
- Describe some of the key ICAO developments that helped shape international aviation.
- Describe some of the early federal legislation in the United States that helped shape the FAA and the airline industry during its formative years.
- Explain why inspector workload has been greatly affected since airline deregulation.
- Discuss the evolution of OSHA and the EPA.
- List and discuss major OSHA standards that are of importance to aviation operations.
- List and discuss major EPA laws that are of importance to aviation operations.

INTRODUCTION

The truth is that the government's role in safety is neither a glamorous nor captivating topic of discussion in the commercial aviation community. However, the discourse is a necessity since regulation and official guidance are critical components of the aviation industry. Governmental agencies have a key responsibility to promote safe operations to protect everyone coming into contact with aviation operations.

with aviation operations.

A sad fact about government regulatory efforts is that poor human decisions can result in regulatory protections being bypassed and can produce a serious accident. Governmental safety guidance, be it compulsory or advisory in nature, is one of the most important defenses against human error, but only if followed. With a single poor choice, all the imposed safeguards disappear.

An even uglier truth, though, is that much of the safety produced by government agencies are the result of *blood priority*. By this we mean that, historically, if lives had not been lost from an airplane accident there is often little chance that changes would have been made to existing policies. Tragically, it has traditionally taken the spilling of blood to modify government regulations. Although this process is slowly changing as the industry and regulators increasingly value the concepts of proactive safety covered in Chapter 7, the process is indeed very slow to change.

This chapter explores the role of government agencies, such as the International Civil Aviation Organization (ICAO) and the *Federal Aviation Administration (FAA)*, and how these organizations affect aviation operations. We will cover not only the traditional aviation-focused agencies, but others that also impact aviation safety due to the extended reach of their work, such as the Occupational Safety and Health Administration (OSHA) and the Environmental Protection Agency (EPA). Each section will talk about the background, organization, and rulemaking authority of each agency to give us a better insight into how the rules and regulations come into effect. These organizations are focused primarily on promoting safety before accidents occur, as opposed to the investigation of accidents. The next chapter is dedicated to accident investigation and features the National Transportation Safety Board (NTSB), a U.S. government agency dedicated to such matters.

INTERNATIONAL CIVIL AVIATION ORGANIZATION (ICAO)

The *International Civil Aviation Organization (ICAO)* is a specialized agency of the United Nations and serves as the global forum for international civil aviation. The vision of ICAO is to achieve sustainable growth for the civil aviation systems of the world. To implement this vision, ICAO had the following five strategic objectives for 2014–2016:

- *Safety*. Enhance global civil aviation safety and develop oversight capabilities. The ICAO Global Aviation Safety Plan (GASP) outlines key safety activities.

- *Air Navigation Capacity and Efficiency*. Increase the capacity of the skies and improve the global civil aviation system's efficiency; upgrade air navigation and aerodrome infrastructure for developing new procedures to optimize aviation system performance.
- *Security and Facilitation*. Enhance global civil aviation security and facilitation. Provide leadership in related border security matters.
- *Economic Development of Air Transport*. Foster the development for an economically sound and viable civil aviation system with air transport framework focused on economic policies and supporting activities.
- *Environmental Protection*. Minimize the adverse environmental effects of civil aviation activities.

The reader should note that in the parlance of the United Nations, and therefore ICAO, what many Americans commonly refer to as "countries" or "nations," such as Brazil, Italy, or China, are referred to as "states." This is not to be confused with the common use of the word "States" in the geography of the United States, which refers to geographic territories within the United States.

BACKGROUND: THE CHICAGO CONVENTION

At its beginning in 1944, ICAO set forth aims and objectives in Article 44 as being to develop "the principles and techniques of international air navigation and to foster the planning and development of international air transport." These aims and objectives, as found in Article 44 of the convention, were to:

- Ensure the safe and orderly growth of international civil aviation throughout the world.
- Encourage the arts of aircraft design and operation for peaceful purposes.
- Encourage the development of airways, airports, and air navigation facilities for international civil aviation.
- Meet the needs of the peoples of the world for safe, regular, efficient, and economical air transport.
- Prevent economic waste caused by unreasonable competition.
- Ensure that the rights of Contracting States are fully respected and that every Contracting State has a fair opportunity to operate international airlines.
- Avoid discrimination between Contracting States.
- Promote safety of flight in international air navigation.

- Promote the development of all aspects of international civil aeronautics.

One of the goals of this conference was to obtain a uniformity in international regulations and standards that was previously lacking. Important work was accomplished in the technical field because the *Chicago Convention* paved the way for a common air navigation system throughout the world. The major accomplishments of the Chicago Convention include the following:

- The Convention on International Civil Aviation provided the basis for a complete modernization of the basic public international law of the air.
- Twelve technical annexes were drafted to cover the technical and operational aspects of international civil aviation such as airworthiness of aircraft, air traffic control, telecommunications, and air navigation services.
- Regions and regional offices were established in specific areas where operating conditional and other relevant parameters were comparable.
- At last, with the formation of ICAO, the international community of states had adopted a single unifying body.

ICAO ORGANIZATION

The International Civil Aviation Organization has its headquarters in the beautiful city of Montreal, Canada, as shown in Figure 5-1, with seven regional offices throughout the world. These regional offices are very important for coordinating international aviation policy and standards, especially in third world and developing nations which do not have a modern aviation infrastructure.

FIGURE 5-1 ICAO headquarters in Montreal, Canada. (*Source: Wikimedia Commons*)

The seven ICAO regional offices are located as follows:

- Bangkok, Thailand—Asia and Pacific office
- Cairo, Egypt—Middle East office
- Dakar, Senegal—Western and Central African office
- Lima, Peru—South American office
- Mexico City—North American, Central American, and Caribbean office
- Nairobi, Kenya—Eastern and Southern African office
- Paris, France—European and North Atlantic office

The International Civil Aviation Organization is made up of three governing bodies: an Assembly, a Council, and a Secretariat. The chief officers of ICAO are the President of the Council and the Secretary General.

are the President of the Council and the Secretary General.

The *Assembly* is the first, sovereign governing body of ICAO and meets every 3 years. ICAO's 191 member States and a large number of international organizations are invited to the Assembly which review the complete work of the organization in the economic, legal, and technical fields. Each state is entitled to one vote, and the decisions of the Assembly are decided by a majority of votes cast, except when otherwise provided for in the Convention. The ICAO's 39th triannual assembly was conducted from September 27 to October 7, 2016.

The *Council* is the permanent, second governing body of ICAO, which is elected by the Assembly and is composed of 36 Contracting States. The Assembly elects the council member States using three criteria:

- States of chief importance in air transport
- States which make the largest contribution to the provision of facilities for civil air navigation
- States whose designation will ensure that all major areas of the world are represented (geographic representation)

As its primary governing body, the Council gives continuing direction to the work of ICAO. The primary focus is to adopt and incorporate ICAO Standards and Recommended Practices (SARPs). Today, ICAO manages over 12,000 SARPs across the 19 annexes to the Convention. To develop SARPs, the Council is assisted by the Air Navigation Commission in technical matters, the Air Transport Committee in economic matters, and the Committee on Unlawful Interference in aviation security matters.

The primary work of the Air Navigation Commission is to advise the Council on aviation navigation issues using international experts with appropriate qualifications and experience in this area. It is important to note that these experts are expected to serve worldwide aviation interests and function independently, and not as representatives of their member States.

The *Secretariat* is the third governing body of ICAO headed by the Secretary General and is divided into five main divisions or *bureaus*. An organization chart for the ICAO Secretariat is shown in Figures 5-2 and 5-3. Please see the ICAO Web site, www.icao.int, for the latest changes.

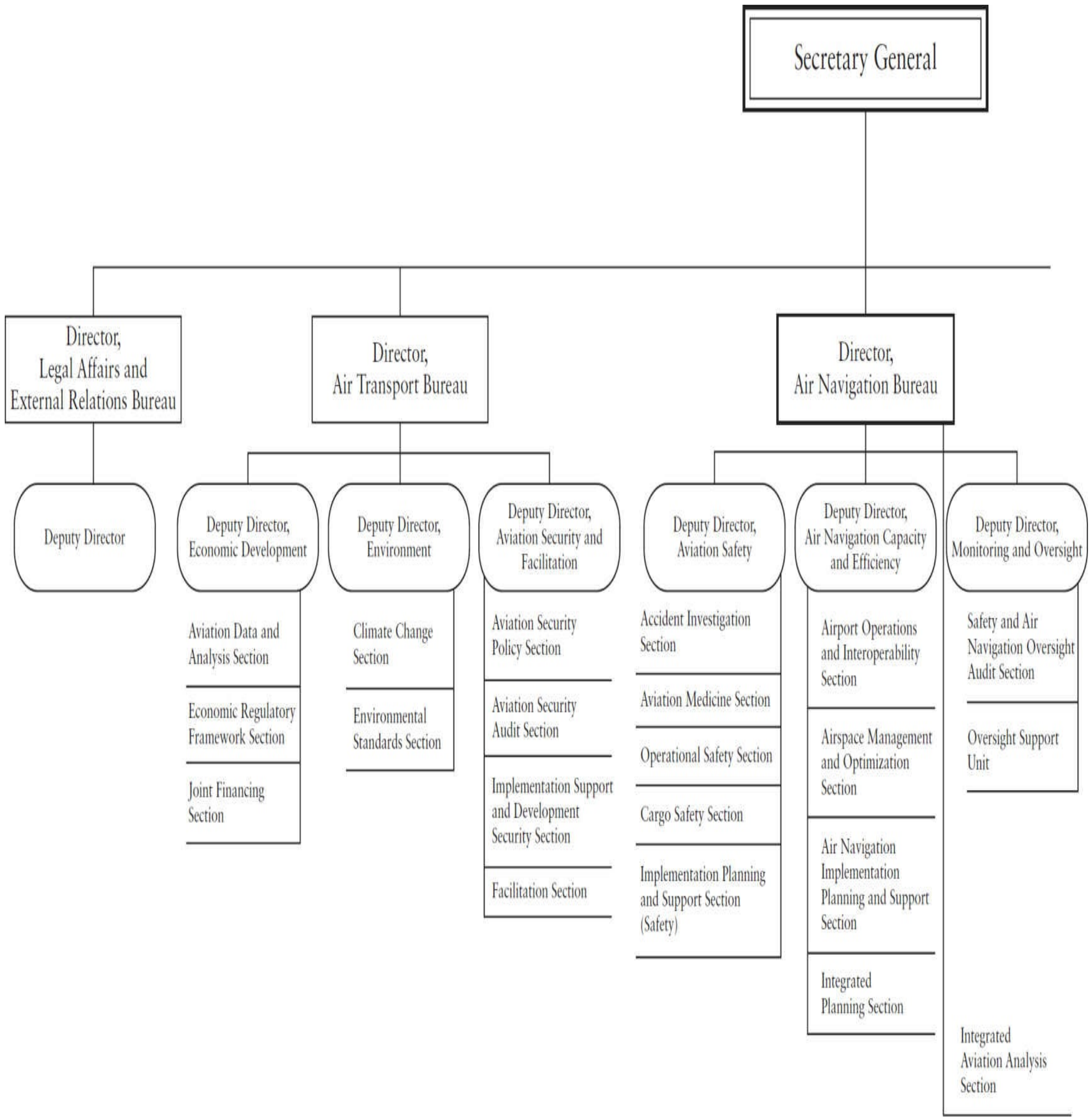

FIGURE 5-2 ICAO organization structure, Part I, as of June 1, 2014. (*Source: ICAO*)

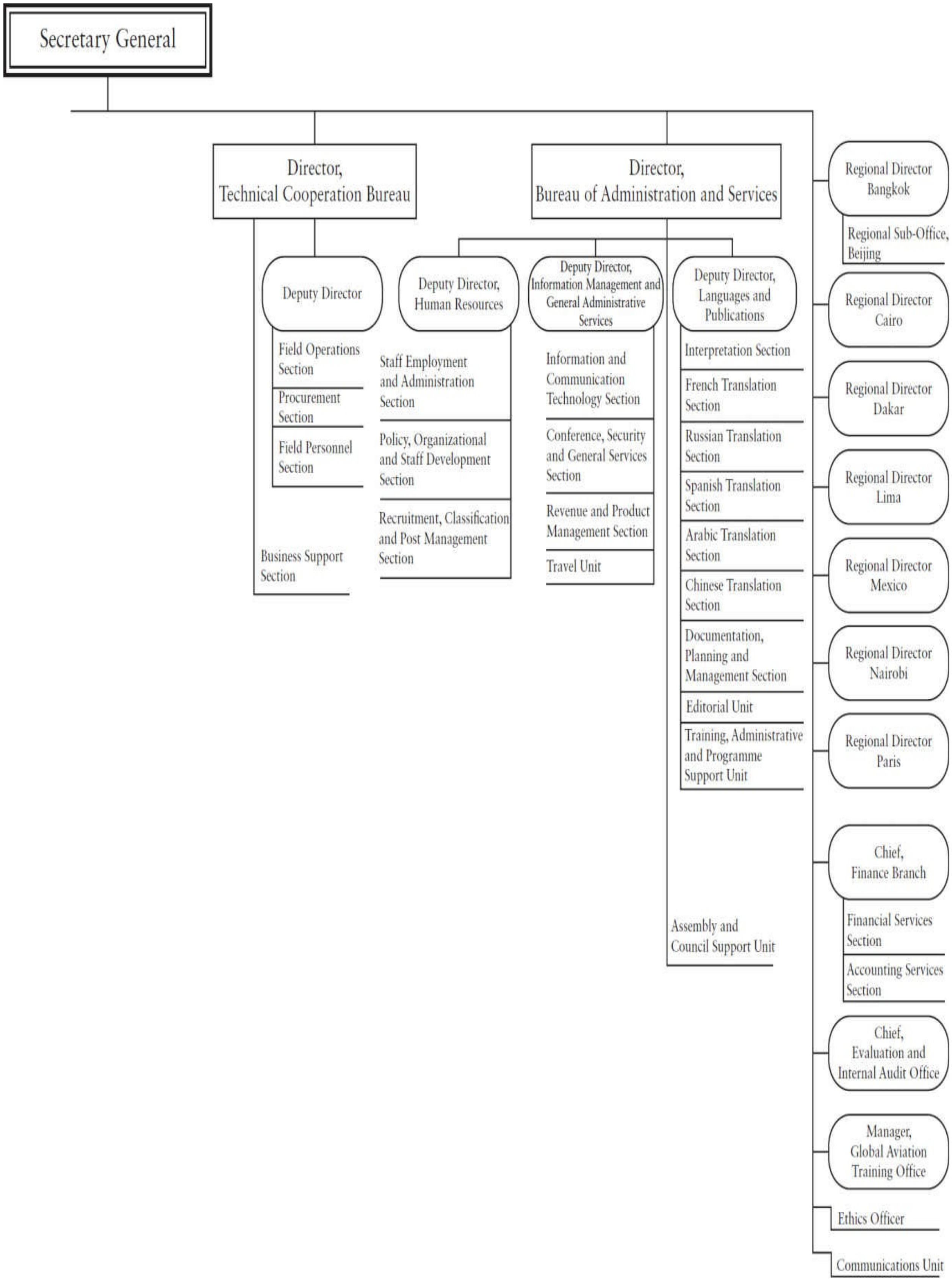
Secretary General
Director, Technical Cooperation Bureau
Deputy Director
Field Operations Section
Procurement Section
Field Personnel Section
Business Support Section
Director, Bureau of Administration and Services
Deputy Director, Human Resources
Staff Employment and Administration Section
Policy, Organizational and Staff Development Section
Recruitment, Classification and Post Management Section
Deputy Director, Information Management and General Administrative Services
Information and Communication Technology Section
Conference, Security and General Services Section
Revenue and Product Management Section
Travel Unit
Deputy Director, Languages and Publications
Interpretation Section
French Translation Section
Russian Translation Section
Spanish Translation Section
Arabic Translation Section
Chinese Translation Section
Documentation, Planning and Management Section
Editorial Unit
Training, Administrative and Programme Support Unit
Assembly and Council Support Unit
Regional Director Bangkok
Regional Sub-Office, Beijing
Regional Director Cairo
Regional Director Dakar
Regional Director Lima
Regional Director Mexico
Regional Director Nairobi
Regional Director Paris
Chief, Finance Branch
Financial Services Section
Accounting Services Section
Chief, Evaluation and Internal Audit Office
Manager, Global Aviation Training Office
Ethics Officer
Communications Unit

FIGURE 5-3 ICAO organization structure, Part II, as of June 1, 2014. (*Source: ICAO*)

The five bureaus are:

- Air Navigation Bureau
- Air Transport Bureau
- Technical Cooperation Bureau
- Legal Affairs and External Relations Bureau
- Administration and Services Bureau

Of these five bureaus, the Air Navigation Bureau (ANB) is by far the most important for the purposes of this text. The Standards (Rulemaking) process of ICAO area kept current by ANB through updating ICAO's governing document, the Annexes of the Chicago Convention.

ICAO RULEMAKING

As indicated on the ICAO Web site, rulemaking uses a language and process with an international focus and lexicon all of its own. ICAO standards and other provisions are primarily developed in the following categories (see www.icao.int):

- *Standards and Recommended Practices (SARPs)*
- *Procedures for Air Navigation Services (PANS)*
- *Regional Supplementary Procedures (SUPPs)*

A *Standard* is defined as any specification for physical characteristics, configuration, material, performance, personnel, or procedure; the uniform application of which is recognized as necessary for the safety or regularity of international air navigation and to which Contracting States must conform in accordance with the Convention. In the event of impossibility of compliance, notification to the Council is compulsory under Article 38 of the Chicago Convention.

A *Recommended Practice* is any specification for physical characteristics, configuration, material, performance, personnel, or procedure; the uniform application of which is recognized as desirable in the interest of safety, regularity, or efficiency of international air navigation, and to which Contracting States will endeavor to conform in accordance with the Convention. Please note

that States are merely invited to inform the Council of noncompliance.

Standards and Recommended Practices are formulated in broad terms and restricted to essential requirements. For complex systems such as communications equipment, SARPs material is constructed in two sections: core SARPs—material of a fundamental regulatory nature contained within the main body of the Annexes, and detailed technical specifications—placed either in Appendices to Annexes or in manuals.

Procedures for Air Navigation Services (or PANS) comprise operating practices and material too detailed for Standards and Recommended Practices—they often amplify the basic principles in the corresponding Standards and Recommended Practices. To qualify for PANS status, the material should be suitable for application on a worldwide basis.

Regional Supplementary Procedures (or SUPPs) have application in the respective ICAO regions. Although the material in SUPPs is similar to that in the Procedures for Air Navigation Services, SUPPs do not have the worldwide applicability of PANS, and are adapted to suit the particular region of the world, through the ICAO regional offices.

Additional Guidance Material is also produced to supplement the SARPs and PANS and to facilitate their implementation. Guidance material is issued as Attachments to Annexes or in separate documents such as manuals, circulars, and lists of designators/addresses. Usually such guidance is approved at the same time as the related SARPs are adopted.

The establishment and maintenance of SARPs and PANS are fundamental tenets of the Chicago Convention and a core aspect of ICAO's mission and role. SARPs and PANS are critical because they provide the fundamental basis for harmonized global aviation safety, efficiency, and worldwide standardization of functional and performance requirements. Typically, it takes about 2 years for an initial proposal for a new or improved SARP or PAN to be formally adopted. The SARP process has been very effective in recent years for ensuring the safe, efficient, and orderly growth of international civil aviation. The reason for success in this area lies in the four "C's" of ICAO international aviation: Cooperation, Consensus, Compliance, and Commitment; that is, cooperation by member States in the formulation of SARPs, consensus in their approval, compliance in their application, and commitment of adherence to the ongoing process. Some definitions are helpful at this point to distinguish between these categories.

Implementation of SARPs/Universal Safety Oversight Audit

PROGRAM. Ensuring that each of the elements in the aviation system meets at least a minimum standard of safety is a key component of regulation at the state level. Under the Convention on International Civil Aviation, the implementation of SARPs lies with Contracting member States. This system has been successful for providing a safe commercial air transport system. To help states in the area of safety, in 1999 ICAO established a Universal Safety Oversight Audit Program. The Program consists of regular, mandatory, systematic, and harmonized safety audits carried out by ICAO in all Contracting States.

The objective of the Safety Oversight Audit is to promote global aviation safety by determining the status of implementation of relevant ICAO SARPs, associated procedures, and safety-related practices. The audits are conducted within the context of critical elements of a State's safety oversight system. These include the appropriate legislative and regulatory framework, a sound organizational structure, technical guidance, qualified personnel, licensing and certification procedures, continued surveillance, and the resolution of identified safety concerns.

NEW ICAO ANNEX 19, SAFETY MANAGEMENT

During the ICAO High-level Safety Conference 2010, the development of an Annex dedicated exclusively to Safety Management was recommended. It was desirable to consolidate all safety requirements into one annex and elevate Safety Management Systems to the "Standard" level. The benefits of this approach include the following:

- Address safety risks proactively.
- Manage and support strategic regulatory and infrastructure developments.
- Reinforce the role played by the State in managing safety at the State level, in coordination with service providers.
- Stress the concept of overall safety performance in all domains.

The Safety Management Systems (SMS) framework encompasses four components (Pillars) for the State Safety Program (SSP):

1. Safety policy and objectives
2. Safety risk management
3. Safety assurance
4. Safety promotion

However, there is some inconsistency in the maturity level of state programs. Larger states may be able to invest significant resources into their SMS programs, while this may not be possible for smaller states that are just now beginning to establish safety management programs at a national level. A small state does not necessarily have to have a large-scale program already in place to start a safety management program, as required by ICAO. Instead, smaller members of ICAO may:

- Use published data on worldwide accidents and causal factors and consider how those many differ in their state.
- Hold meetings to identify and find risks based on published data and according to safety managers at each air carrier.
- Use free safety information available from several sources to implement SSP regulatory programs.

Additional information on the many benefits of SMS will be provided in Chapter 12 of this book.

ICAO Worldwide Safety Ratings

In contrast to the controversy over who should regulate the safety for flight operations, the United States acts as its own watchdog for ensuring other countries who want to operate within its borders comply with the safety standards established by ICAO. Under the International Aviation Safety Assessment (IASA), the FAA determines whether another country's oversight of its carriers operating or codesharing with the United States complies with Annex 1 (Personnel Licensing), Annex 6 (Operation of Aircraft), and Annex 8 (Airworthiness of Aircraft) to the Chicago Convention. For example, at the end of 2015, IASA downgraded Thailand's safety rating since it was not in compliance with ICAO safety standards. At present, existing Thai air operators can still operate in the United States, but cannot provide new, additional services until they meet all ICAO safety requirements.

THE FEDERAL AVIATION ADMINISTRATION (FAA)

The Federal Aviation Administration is a U.S. government agency with primary responsibility for the safety of civil aviation. The FAA's major roles and responsibilities as stated on its Web site include:

- Regulating civil aviation to promote safety.
- Encouraging and developing civil aeronautics, including new aviation technology.
- Developing and operating a system of air traffic control (ATC) and navigation for both civil and military aircraft. Figure 5-4 shows an air traffic controller at work.

FIGURE 5-4 An FAA air traffic controller. (*Source: FAA*)

- Researching and developing the National Airspace System and civil aeronautics.
- Developing and carrying out programs to control aircraft noise and other environmental effects of civil aviation.
- Regulating U.S. commercial space transportation.

Background

The FAA is responsible for performing several activities that are in support of

The FAA is responsible for performing several activities that are in support of the previously mentioned functions. These activities as reproduced from the FAA Web site include the following:

- *Safety regulation*. The FAA issues and enforces regulations and minimum standards covering the manufacture, operation, and maintenance of aircraft. The agency is responsible for the rating and certification of airmen and airports serving air carriers.
- *Airspace and air traffic management*. The safe and efficient utilization of the navigable airspace is a primary objective of the FAA. The agency operates a network of airport towers, air route traffic control centers, and flight service stations. It develops air traffic rules, and assigns and controls the use of airspace.
- *Air navigation facilities*. The FAA is responsible for the construction and installation of visual and electronic aids to air navigation and for the maintenance, operation, and quality assurance of these facilities. Other systems maintained in support of air navigation and air traffic control include voice/data communications equipment, radar facilities, computer systems, and visual display equipment at flight service stations.
- *Civil aviation abroad*. The FAA promotes aviation safety and encourages civil aviation abroad. Activities include exchanging aeronautical information with foreign authorities; certifying foreign repair shops, airmen, and mechanics; providing technical aid and training; negotiating bilateral airworthiness agreements; and taking part in international conferences.
- *Commercial space transportation*. The agency regulates and encourages the U.S. commercial space transportation industry. It licenses commercial space launch facilities and private sector launching of space payloads on expendable launch vehicles.
- *Research, engineering, and development*. The FAA does research on and develops the systems and procedures needed for a safe and efficient system of air navigation and air traffic control. The agency supports development of improved aircraft, engines, and equipment. It also conducts aeromedical research and evaluations of items such as aviation systems, devices, materials, and procedures.
- *Other programs*. The FAA provides a system for registering aircraft and recording documents affecting title or interest in aircraft and their components. Among other activities the agency administers an aviation insurance program, develops specifications for aeronautical charts, and

publishes information on airways, airport services, and other technical subjects in aeronautics.

FAA ORGANIZATION

The largest agency of the U.S. Department of Transportation (DOT), the FAA, has authority to regulate and oversee all aspects of civil aviation with an annual budget around $16 billion. The FAA-stated mission is to provide the safest, most efficient aerospace system in the world. Its organizational chart is shown in Figures 5-5 and 5-6, split laterally down the middle in order to legibly fit on these pages. Please see the FAA Web site, www.faa.gov, for the latest information.

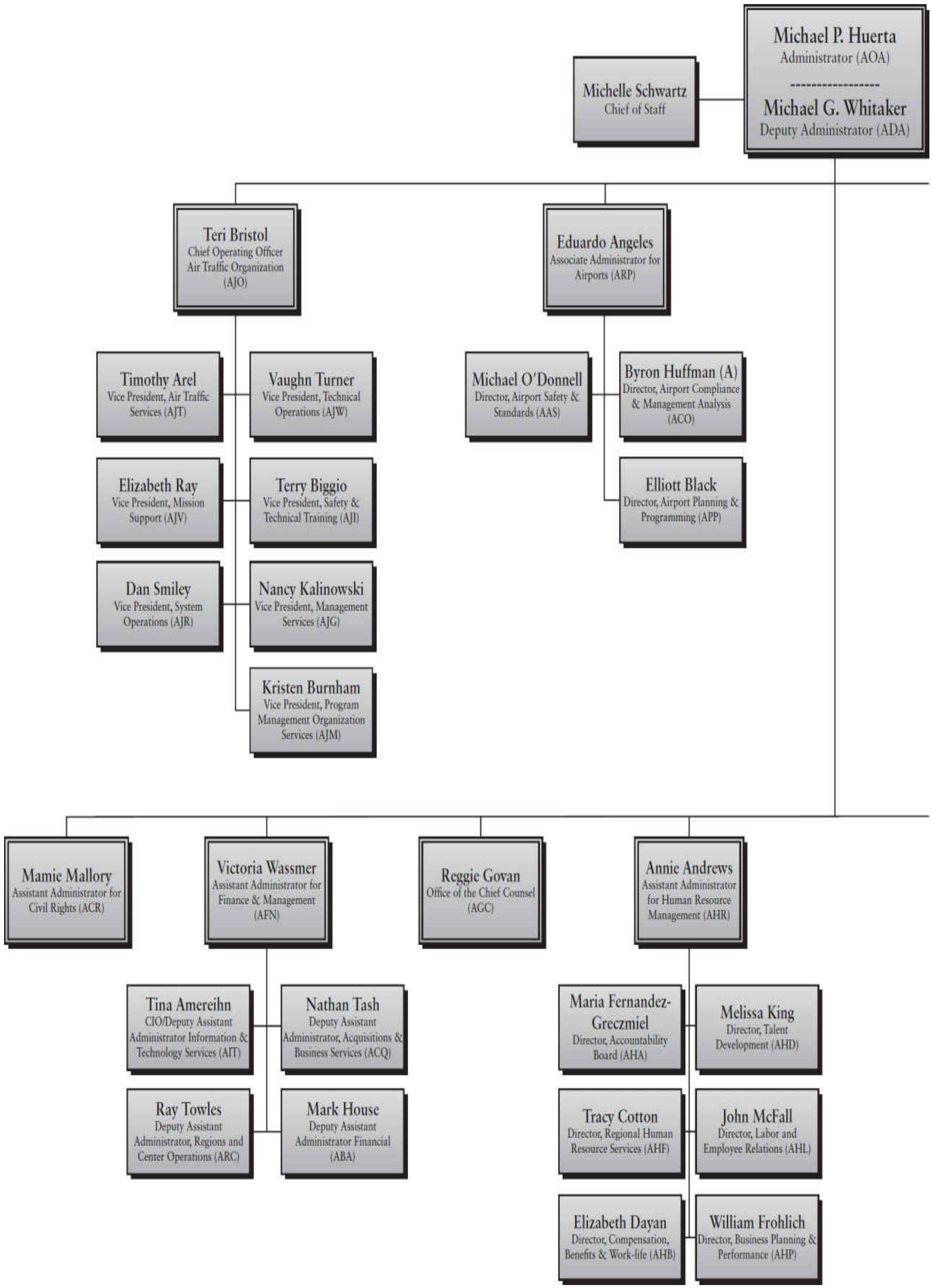
Michael P. Huerta
Administrator (AOA)
Michael G. Whitaker
Deputy Administrator (ADA)
Michelle Schwartz
Chief of Staff
Teri Bristol
Chief Operating Officer Air Traffic Organization (AJO)
Eduardo Angeles
Associate Administrator for Airports (ARP)
Timothy Arel
Vice President, Air Traffic Services (AJT)
Vaughn Turner
Vice President, Technical Operations (AJW)
Elizabeth Ray
Vice President, Mission Support (AJV)
Terry Biggio
Vice President, Safety & Technical Training (AJI)
Dan Smiley
Vice President, System Operations (AJR)
Nancy Kalinowski
Vice President, Management Services (AJG)
Kristen Burnham
Vice President, Program Management Organization Services (AJM)
Michael O'Donnell
Director, Airport Safety & Standards (AAS)
Byron Huffman (A)
Director, Airport Compliance & Management Analysis (ACO)
Elliott Black
Director, Airport Planning & Programming (APP)
Mamie Mallory
Assistant Administrator for Civil Rights (ACR)
Victoria Wassmer
Assistant Administrator for Finance & Management (AFN)
Reggie Govan
Office of the Chief Counsel (AGC)
Annie Andrews
Assistant Administrator for Human Resource Management (AHR)
Tina Amereihn
CIO/Deputy Assistant Administrator Information & Technology Services (AIT)
Nathan Tash
Deputy Assistant Administrator, Acquisitions & Business Services (ACQ)
Ray Towles
Deputy Assistant Administrator, Regions and Center Operations (ARC)
Mark House
Deputy Assistant Administrator Financial (ABA)
Maria Fernandez-Greczmiel
Director, Accountability Board (AHA)
Melissa King
Director, Talent Development (AHD)
Tracy Cotton
Director, Regional Human Resource Services (AHF)
John McFall
Director, Labor and Employee Relations (AHL)
Elizabeth Dayan
Director, Compensation, Benefits & Work-life (AHB)
William Frohlich
Director, Business Planning & Performance (AHP)

FIGURE 5-5 Left half of the FAA organization chart. (*Source: FAA*)

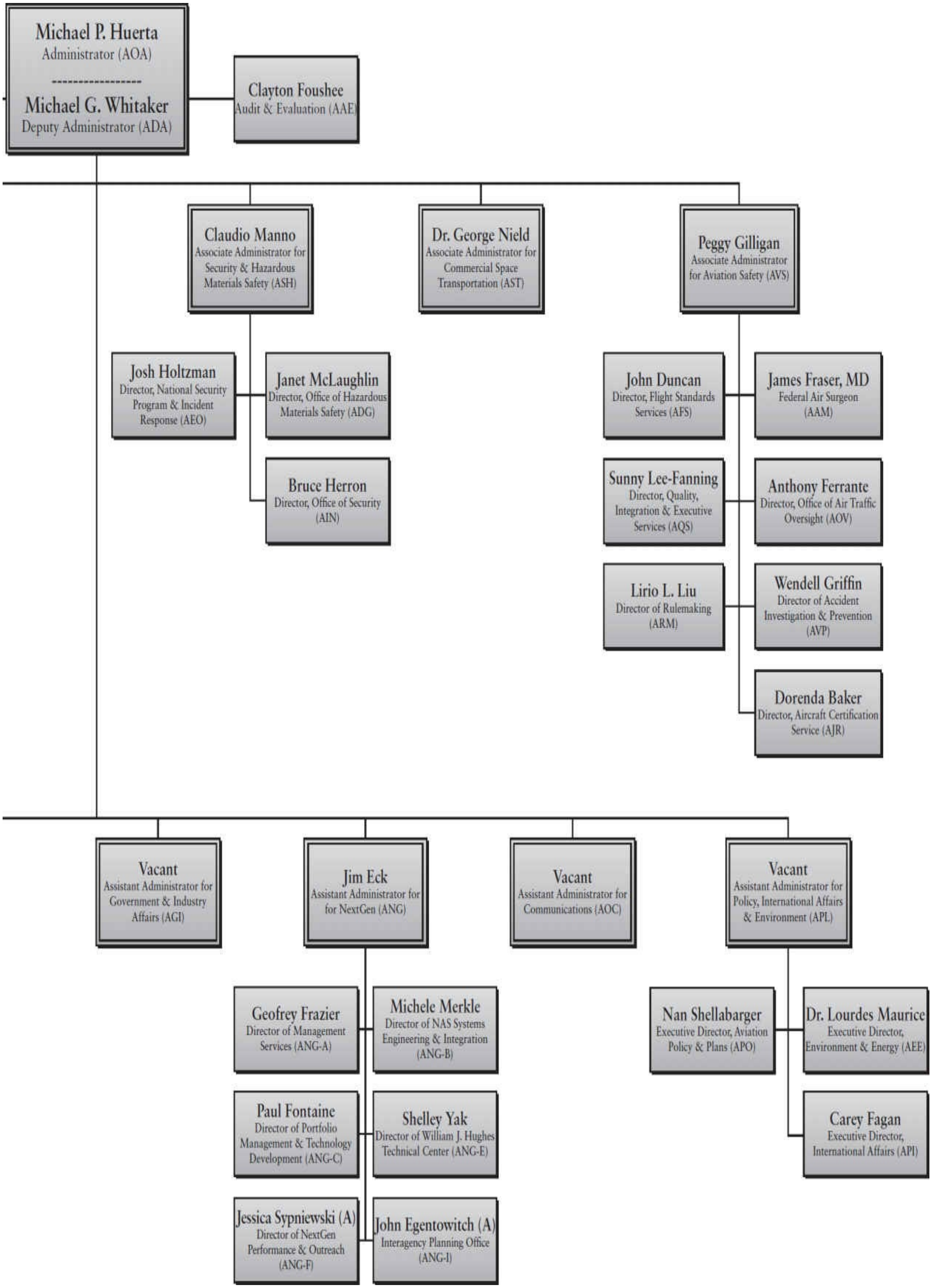
Michael P. Huerta
Administrator (AOA)
Michael G. Whitaker
Deputy Administrator (ADA)
Clayton Foushee
Audit & Evaluation (AAE)
Claudio Manno
Associate Administrator for Security & Hazardous Materials Safety (ASH)
Dr. George Nield
Associate Administrator for Commercial Space Transportation (AST)
Peggy Gilligan
Associate Administrator for Aviation Safety (AVS)
Josh Holtzman
Director, National Security Program & Incident Response (AEO)
Janet McLaughlin
Director, Office of Hazardous Materials Safety (ADG)
Bruce Herron
Director, Office of Security (AIN)
John Duncan
Director, Flight Standards Services (AFS)
James Fraser, MD
Federal Air Surgeon (AAM)
Sunny Lee-Fanning
Director, Quality, Integration & Executive Services (AQS)
Anthony Ferrante
Director, Office of Air Traffic Oversight (AOV)
Lirio L. Liu
Director of Rulemaking (ARM)
Wendell Griffin
Director of Accident Investigation & Prevention (AVP)
Dorenda Baker
Director, Aircraft Certification Service (AJR)
Vacant
Assistant Administrator for Government & Industry Affairs (AGI)
Jim Eck
Assistant Administrator for for NextGen (ANG)
Vacant
Assistant Administrator for Communications (AOC)
Vacant
Assistant Administrator for Policy, International Affairs & Environment (APL)
Geofrey Frazier
Director of Management Services (ANG-A)
Michele Merkle
Director of NAS Systems Engineering & Integration (ANG-B)
Paul Fontaine
Director of Portfolio Management & Technology Development (ANG-C)
Shelley Yak
Director of William J. Hughes Technical Center (ANG-E)
Jessica Sypniewski (A)
Director of NextGen Performance & Outreach (ANG-F)
John Egentowitch (A)
Interagency Planning Office (ANG-I)
Nan Shellabarger
Executive Director, Aviation Policy & Plans (APO)
Dr. Lourdes Maurice
Executive Director, Environment & Energy (AEE)
Carey Fagan
Executive Director, International Affairs (API)

FIGURE 5-6 Right half of the FAA organization chart. (*Source: FAA*)

HEADQUARTERS OFFICES

OFFICE OF THE ADMINISTRATOR This office provides overall direction and supervision of the Agency and reports directly to the Secretary of Transportation (DOT), a cabinet level position. Within this office is a Deputy Administrator Chief of Staff and the Audit and Evaluation Office.

The primary FAA lines of business and major offices (www.faa.gov) include the following:

1. The *Air Traffic Organization (ATO)* is the operational arm of the FAA. It is responsible for providing safe and efficient air navigation services to 30.2 million square miles of airspace. This represents more than 17% of the world's airspace and includes all of the United States large portions of the Atlantic and Pacific Oceans, and the Gulf of Mexico. Its stakeholders are commercial and private aviation and the military, and its employees are the service providers—the 35,000 controllers, technicians, engineers, and support personnel whose daily efforts keep aircraft moving safely through the nation's skies.

ATO offices and services include the following:

- Safety and Technical Training
- System Operations
- Air Traffic Services
- Technical Operations
- Mission Support
- Management Services
- Program Management Organization

2. *Aviation Safety (AVS)* is an organization responsible for the certification, production approval, and continued airworthiness of aircraft; certification of pilots, mechanics; and others in safety-related positions. Aviation Safety is also responsible for the following:

- Certification of all operational and maintenance enterprises in domestic civil aviation
- Certification and safety oversight of approximately 7,300 U.S. commercial airlines and air operators
- Civil flight operations

- Developing regulations

AVS offices and services include the following:

- *Flight Standards Service*
- Federal Air Surgeon
- Quality, Integration, and Executive Service
- Air Traffic Oversight
- Rulemaking (discussed below)
- Accident Investigation and Prevention
- Aircraft Certification Service

3. *Airports (ARP)*. The Airports organization provides leadership in planning and developing a safe and efficient national airport system. The office has responsibility for all programs related to airport safety and inspections and standards for airport design, construction, and operation (including international harmonization of airport standards). Each year, the office awards $3.5 billion in airport grants and approves passenger facility charge collections totaling $2 billion. The office also is responsible for national airport planning and environmental and social requirements and establishes policies related to airport rates and charges, compliance with grant assurances, and airport privatization.

ARP major offices and services include the following:

- Airport Safety and Standards
- Airport Compliance and Management Analysis
- Airport Planning and Programming

4. *Office of the Next Generation Air Transportation System (NextGen)* (www.faa.gov/nextgen).

As provided on the FAA web page, NextGen is a transformative change in the management and operation of how we fly, which will reduce delays, save fuel, and lower carbon emissions. This comprehensive initiative integrates new and existing technologies, including satellite navigation and advanced digital communications. Airports and aircraft in the U.S. National Airspace System (NAS) will be connected to NextGen's advanced infrastructure and will continually share information in real time to improve air transportation's safety, speed, efficiency, and environmental impacts. The combined initiatives that make up NextGen will provide a better travel experience.

The NextGen Office coordinates NextGen initiatives, programs, and policy development across the various FAA lines of business and staff offices. The

office also works with other U.S. federal and state government agencies, the FAA's international counterparts, and members of the aviation community to ensure harmonization of NextGen policies and procedures.

5. *Primary FAA Technical Centers*

- William J. Hughes Technical Center—Atlantic City, NJ
    - The FAA William J. Hughes Technical Center (commonly known as the FAA Tech Center) is the nation's premier air transportation system laboratory. The Technical Center's highly technical and diverse workforce conducts tests and evaluations, verification and validation, sustainment of the FAA's full spectrum of aviation systems, and develops scientific solutions to current and future air transportation safety challenges by conducting applied research and development. Technical Center engineers, scientists, mathematicians, and technical experts utilize a robust, one-of-a-kind, world class laboratory environment to identify integrated system solutions for the modernization and sustainment of the NAS, and for delivering NextGen operational capabilities.
- Mike Monroney Aeronautical Center, Oklahoma City, OK
    - The Mike Monroney Aeronautical Center is one of the largest FAA centers in the country and home of the following offices:
        - FAA Logistic Center provides consulting, engineering, repair, distribution, and technical support for air traffic control services in the United States and 44 different countries.
        - FAA Academy is the principal training facility of the FAA. All FAA air traffic controllers receive their basic training at the Academy.
        - The Civil Aerospace Medical Institute (CAMI) is the medical certification, education, research, and occupational medicine wing of the FAA Office of Aerospace Medicine.

Additional information on each of the offices together with their contacts is available on the current FAA Web site. Some of the office functions that are important to the scope and intent of this text will be discussed in greater detail throughout the book.

FAA Safety Inspection Program

Aviation safety depends in part on the quality and thoroughness of the airlines' maintenance programs and on oversight and surveillance by safety inspectors of the FAA. Even though the frequency of maintenance-related accidents has not increased since 1978, airline deregulation has been accompanied by increasing

increased since 1978, airline deregulation has been accompanied by increasing concern that maintenance standards might have been lowered at some carriers and that pressures of the marketplace might lead to unsafe operating practices. At the same time, deregulation has increased the stress on FAA inspection programs. The existing regulatory inspection program, with its local and regional structure, does not have sufficient flexibility to adapt to a dynamic industry environment.

The 78 *Flight Standards District Offices (FSDOs)* nationwide handle the dual functions of safety inspection and advice for airlines. In addition to scheduled airline surveillance, the local offices are responsible for the safety inspections of nonscheduled air taxis and other operations, such as flight schools, engine overhaul shops, and private pilots. An air carrier's operating certificate is held at a specific flight standards office, typically the one nearest the carrier's headquarters or primary operations or maintenance base. For each carrier, a principal inspector is assigned to operations (flights, training, and dispatch), another is assigned to airworthiness (maintenance), and a third may be assigned to avionics (navigation and communications equipment). For large airlines, each of the principal inspectors can have assistants.

Local FSDOs conduct several types of inspections at each airline: an inspection of maintenance functions and an inspection of operations. Inspectors periodically conduct maintenance-base inspections, which focus on the records kept by an airline. For example, records demonstrating that an airline has complied with airworthiness directives might be inspected. Inspectors conduct shop inspections to observe maintenance procedures and carry out ramp inspections to observe the airworthiness of aircraft. A similar operations-base inspection focuses on records containing the hours of training provided, the checkrides performed for pilots, and the rest periods between duty shifts as required by regulations. Furthermore, en route inspections involve observations of actual flight operations, with the inspector riding in the jumpseat in the cockpit.

Base inspections are preannounced. There is a tendency to focus on records rather than to probe deeply into the data underlying carrier records concerning maintenance, training, and flight crew logs. Inspectors at the local level try to work with air carriers to achieve compliance when they find discrepancies. Violations and fines are viewed as a last resort.

Every major airline has a reliability program that monitors maintenance activities and looks for emerging problems. This has been reinforced by the recent ICAO and FAA emphasis on SMS, which will be discussed later in this textbook. For example, most airlines monitor engine temperatures, oil

consumption, and the metal content of oil. They then use these tests to determine when an individual engine needs to be overhauled or repaired. Some airlines also use statistical measures such as the number of engines requiring premature overhaul, engines that are shut down in flight, the number of mechanical discrepancies that are left outstanding at flight time, and the rate at which these discrepancies are cleared. In some companies, analysts search for adverse trends that might indicate, for example, a shop procedure that needs to be revised, both to ensure safety and to reduce maintenance expense. Some FSDOs have taken advantage of these statistical data to monitor the effectiveness of airline maintenance. In some cases, flight standards inspectors have encouraged airlines to set up or expand their statistical reliability programs.

AVIATION SAFETY INSPECTOR WORKLOAD. The inspector workload has been affected greatly by airline deregulation. Whenever a new airline is formed, an airline has placed a new aircraft type into service, or two airlines have merged, flight standards have been obliged to devote resources to certificating the new or changed air carrier. Certification involves page-by-page approval of the airline's operations and maintenance manuals, checkrides for the airline's senior pilots, and assessment of actual operations as a whole.

Certification is an activity that competes for inspectors' time within the entire safety inspection program. Because it is a potential bottleneck in the establishment of new and changing airlines, requests for certification divert resources from other surveillance activity and usually bring pressure on the FAA to address the certification on a priority basis. Only after all certification requests have been fulfilled, any remaining inspector time is then devoted to surveillance.

The situation has improved in recent years. However, the large number of airline mergers has affected the flight standards personnel in a unique way. When airlines merge, the acquired carrier often is kept intact as an operating entity. Such a situation often creates complications due to differences in aircraft types, crew training, and maintenance programs. Consequently, the FAA inspection force assigned to the acquiring carrier might become responsible for the operations of a carrier that is much different and is located in another region. Since principal inspectors may then be far away from large operational components of the newly merged airline, there is a greater dependence on inspections by the FAA offices that happen to be near the remote components. Such offices often bear the burden of performing the inspections after mergers. Inspections performed by one office on another office's carrier are called geographic inspections by the FAA.

FAA RULEMAKING

Over the past 50 years, numerous reports have documented the delays in the FAA rulemaking process. There is no question that rulemaking is extremely time-consuming and complex, requiring careful consideration of the impact of proposed rules on the public, aviation industry, the economy, and the environment. The U.S. Government Accountability Office has reported that after formally initiating a rule, the FAA took an average of 30 months to complete the rulemaking, and 20% of the rules took over 10 years or longer to complete.

In recent years, difficult rulemaking issues such as changes to the Airline Transport Pilot qualifications and the operation of small Unmanned Aircraft Systems (UAS or drones) have taken several years to develop. Often it takes public outcry and political pressure to move the process forward such as seen in the wake of the Colgan Air Commuter flight crash in Buffalo, New York, in February 2009.

In general, all government administrative rulemaking is governed under the Administrative Procedures Act (APA), which requires advance notice and opportunity for the public and industry to comment before a rule is issues or amended. Under the Federal Advisory Committee Act, the FAA obtains advice and recommendations from industry concerning the full range of its rulemaking activity, including all aviation-related issues such as air carrier operations, airman and aircraft certification, airports, and noise abatement. The primary committee chartered by the FAA for this purpose is called the *Aviation Rulemaking Advisory Committee (ARAC)* whose primary purpose is to provide the public an earlier opportunity to participate in the FAA rulemaking process before the formal APA notification period begins.

STEPS IN THE FORMAL RULEMAKING PROCESS. The formal FAA rulemaking procedures are provided in Question and Answer format in 14 CFR Part 11. A diagram of the FAA's process is provided in Figure 5-7.

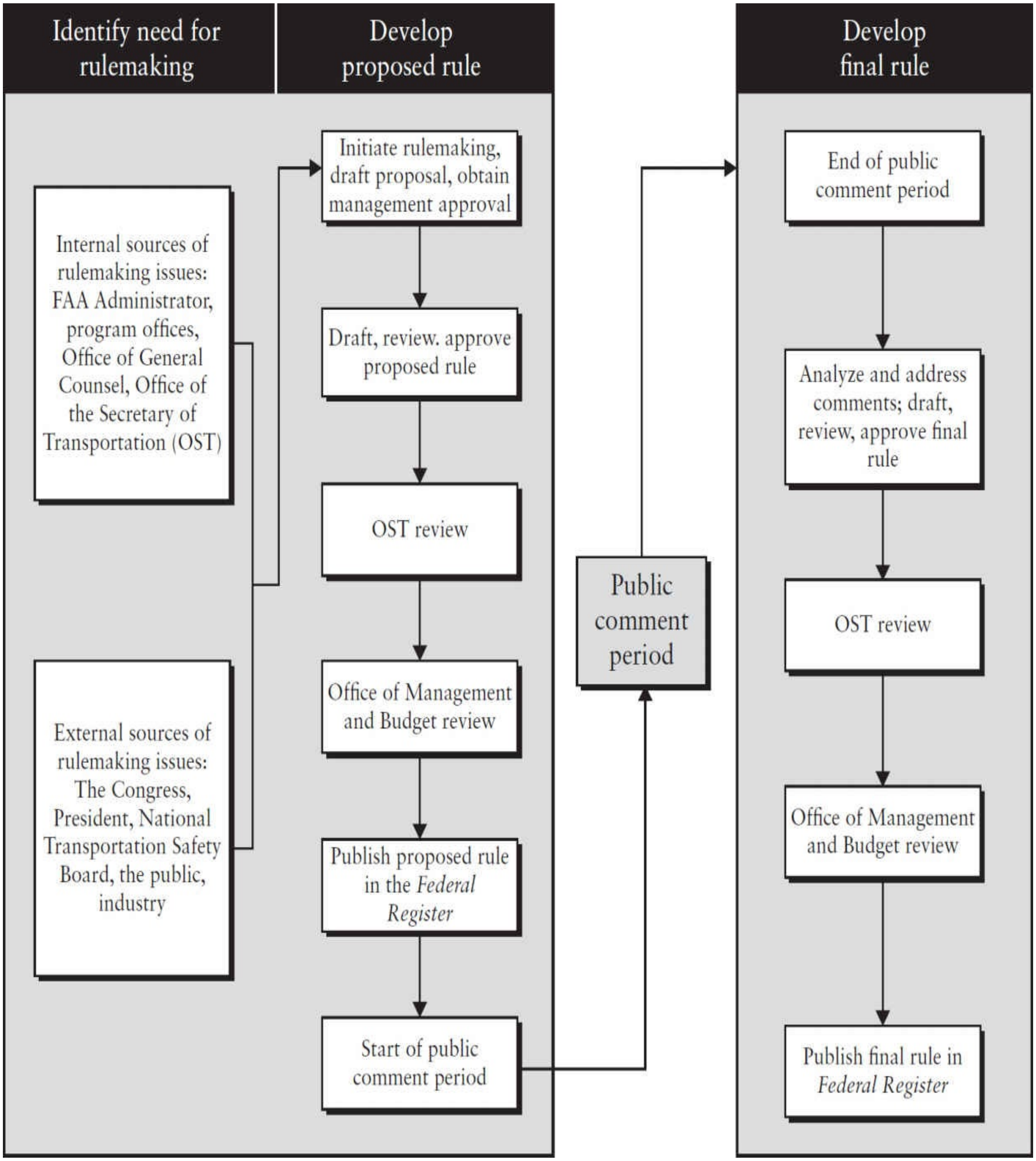

FIGURE 5-7 FAA rulemaking process for significant rules. (*Source: GAO*)

Most analysts of the FAA rulemaking process agree that the area most in need of improvement is that of timeliness in identifying and responding to safety issues. Critics complain that excessive delays in the rulemaking process complicate new or amended certification programs and make them more costly. They complain of excessive rewriting and divergent rules for different aircraft

categories when such rules should be identical. Some critics blame the Office of the Secretary of Transportation and the Office of Management and Budget (OMB) for much of the delay.

The problem of rulemaking delay seems to lie with the whole process, not just the DOT, the OMB, or the FAA. In any case, most analysts agree that the rulemaking process needs to be streamlined. The essential steps in developing sound public safety policy must be identified, and the rest eliminated.

DUAL MANDATE FOR COMMERCIAL SPACE OPERATIONS. When the FAA was established, its jurisdiction for rulemaking included promoting both the growth of industry and safety. As the industry grew, though, the FAA eventually moved toward focusing solely on safety. However, a similar dual mandate has appeared again due to a new industry that is emerging and which also has close ties to the FAA: commercial space operations. Once again, the FAA is responsible for promoting spaceflight operations and overseeing its safety. Under the Office of Commercial Space Transportation (FAA-AST), regulations are being created to ensure protection of the public, property, and national security and foreign policy interests of the United States during commercial launch or reentry activities, and to encourage, facilitate, and promote U.S. commercial space transportation.

AIRWORTHINESS DIRECTIVES

When the need arises, the FAA releases airworthiness directives. These notices are legally enforceable rules that aim to correct an unsafe condition that arise in a particular model of aircraft, engine, avionics, or any other system in the airplane that needs to be corrected. For example, in April 2016 the FAA issued an airworthiness directive requiring Boeing 787 operators to update flight manuals due to the prevalence of bad airspeed data. The FAA made this move after there had been three reports of airspeed anomalies.

In each reported case, the displayed airspeed rapidly dropped significantly below the actual airplane airspeed. The directive warned the pilots not to use abrupt control inputs in case of erroneous airspeed indications, since such inputs at high speeds could structurally damage the aircraft, and also to disconnect the autopilot before making any manual flight control inputs. A current list of FAA Airworthiness Directives can be found on its Web site.

EXAMPLE OF FAA RULEMAKING PROCESS: THE ATP-CTP

To better understand the regulatory system of the government, it is helpful to

To better understand the regulatory system of the government, it is helpful to illustrate an example of the FAA rulemaking process in action. One of the worst aviation accidents in recent U.S. history happened in February 2009 when a Bombardier Dash-8 Q400 operating as Colgan Air Flight 3407 crashed near Buffalo, New York, killing all 49 passengers and crew. In the aftermath of the tragedy, the family of the victims campaigned to set higher industry standards for airline pilots.

After intense lobbying from the victim's family and other legislative pressures, in 2010 the U.S. Congress passed a bill titled the Airline Safety and Federal Administration Extension Act of 2010 that required first officers (copilots) operating aircraft under FAA CFR Part 121 to hold an Airline Transport Pilot (ATP) certificate. This bill was signed into law as Public Law 111-216, and airlines were given until August 2013 to comply with the new provision. Up until that time, first officers of such aircraft were only required to possess a commercial pilot certificate, which has lower flight time requirements than an ATP certificate.

Before bringing this regulation into effect, the FAA Advisory and Rulemaking Committee drafted a report that identified a knowledge and flight experience gap stating that the quantity of training does not necessarily equal quality of training. From these findings, Public-Law 111-216 was created. It was broken down into two parts:

- *Section 216*. This set the requirement for FAA to complete rulemaking to require all Part 121 pilots to hold an ATP certificate and have a set amount of multiengine flight time.
- *Section 217*. Under this section, the FAA would create regulations for revising the requirements for the ATP certificate and allow a reduction to the 1,500-hour ATP requirement for a pilot who had received certain academic coursework.

The FAA then published Public Law 111-16 for public comment. It elicited more than 550 comments, 120 of which were specific to the ATP-CTP before being made a final rule. The timeline below gives insight into the lengthy process and the pace for the changes:

- *February 2009*. Colgan Air Flight 3407 accident.
- *February 2010*. Advance notice about a regulation change for first officers.
- *July 2010*. Aviation rulemaking committee was formed to investigate current requirements for first officers.

- *August 2010*. Law 111-216 was published regarding changes that would be made to current requirements.
- *February 2012*. The FAA released a notice for proposed rulemaking to solicit public comments about the proposed changes.
- *July 15, 2013*. Final ruling went into effect.

Some industry and union groups have expressed concern that the changes required by this legislation have created a pilot shortage at the regional airline level because it significantly increased the amount of flight time pilots must have before making the next step in their career and joining the airline industry. While previously pilots could become an airline first officer as long as they had 250 hours of flight experience and a commercial pilot's certificate, now the increase in hours required to 1,500 imposes a significantly longer time during which pilots must accrue much more flight experience prior to being accepted to fly for the airlines. This delay can be several years' worth of time, often spent flight instructing or in some other time building endeavor, in order to reach the required 1,500 hours. Some regional airlines have even made the bold claim that they have been unable to staff the flight schedule with pilots and, as a consequence, have had to cancel flights and park aircraft.

There are special provisions in the new regulations that do provide some relief to the increased flight hour requirements. Pilots who have met certain rigorous requirements following FAA-approved curricula at certain aviation universities or similar institutions of higher learning may have the required time reduced from 1,500 flight hours to 1,000 flight hours. This provision requires a minimum of 60 academic credits in aviation courses, 200 hours of cross-country flight time, and obtaining one's instrument rating and commercial pilot's license at the same institution, plus completion of a special *Air Transport Pilot Certification Training Program (ATP-CTP)* that includes 6 hours of training in Level C or D (full motion) simulators.

RECENT FAA REGULATORY DEVELOPMENTS

FAIR TREATMENT OF EXPERIENCED PILOTS ACT. Since 1959, the FAA had set an age limit of 60 for pilots operating under *FAR Part 121*. This was known as the "Age 60 retirement rule." However, in November 2006, ICAO raised the maximum age for certain pilots in international operations from age 60 to 65. Following this change, the Fair Treatment of Experienced Pilots Act went into effect in 2007, mandating retirement of pilots at age 65. This limit though, only

applies to FAR Part 121 operations, leaving open the debate open for whether or not *FAR Part 135* operations should also follow this rule.

NEW FLIGHT AND DUTY TIME REST REQUIREMENTS. In January 2012 the FAA created *FAR Part 117* entitled, "Flight and Duty Time Limitations and Rest Requirements," which replaced previous similar regulations for FAR Part 121 airline passenger operations. This rule was the first major revision to duty and rest guidance in 60 years. After many years of research and work to improve commercial aviation safety, the rule was passed to prevent *fatigue* and enforce compliance with mandatory pilot rest periods. It recognizes that universal factors cause fatigue and regulates these factors to mitigate its effects through a new Fatigue Risk Management System.

Part 117's underlying philosophy is that there is no single component that buffers the risk of fatigue to an acceptable level, rather a system approach must be adopted that makes both the carrier and crewmembers responsible for protecting everyone against the risks of fatigue. Unlike the ATP-CTP requirement that was previously discussed, the foundation of FAR Part 117 is rooted in science. Extensive research was conducted to examine circadian rhythms and how they have an effect on flying performance. The new rule provides the following:

- Establishes varying flight and duty requirements based on what time the pilot's day begins.
- Stipulates the flight duty period, otherwise known as the allowable length of a work period as a function of when the day commences and the number of flight segments expected to be flown. This period ranges from 9 to 14 hours for single crew operations.
- Establishes flight time limits of 8 or 9 hours, depending on the start time of the pilot's entire flight duty period.
- Sets a minimum 10-hour rest period prior to a flight's duty period, which is 2 more hours than the previous rule, and which also requires that 8 of the hours provide for uninterrupted sleep.
- Sets new requirements to address cumulative flight duty and flight time limits for each 28-day period. This also requires that pilots have at least 30 consecutive hours free from duty on a weekly basis, which is 25% more than the previous rule provided.

OCCUPATIONAL SAFETY AND HEALTH

OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION (OSHA)

BACKGROUND

The *Occupational Safety and Health Administration Act of 1970* (OSHA Act) created a new organization under the U.S. Secretary of Labor. The mission of OSHA is to ensure safe and healthful working conditions for working men and women by setting and enforcing standards, and by providing training, outreach, education, and assistance. The OSHA Act covers all employers and employees who do business in the United States, except workplaces already protected by other federal agencies under other federal statutes. This means that OSHA's jurisdiction does not extend into the aircraft, but it does apply to all ground, ramp, and airport maintenance operations. Figure 5-8 shows a spray painter applying a primer on an aircraft part in preparation for painting. As can be seen, the painter is wearing goggles and a respirator assembly for protection from fumes. This protective equipment illustrates some of the requirements stipulated by OSHA to keep the workforce free of injury.

FIGURE 5-8 Painter priming an aircraft part in preparation for painting. (*Source: U.S. Navy*)

Osha Organization

Figure 5-9 shows the most recent organizational chart available for OSHA to include depiction of the different directorates, regional offices, and responsible officials. The figure makes for a handy reference when reviewing the organizational elements of this agency. For current information, please visit the OSHA Web site at www.osha.gov.

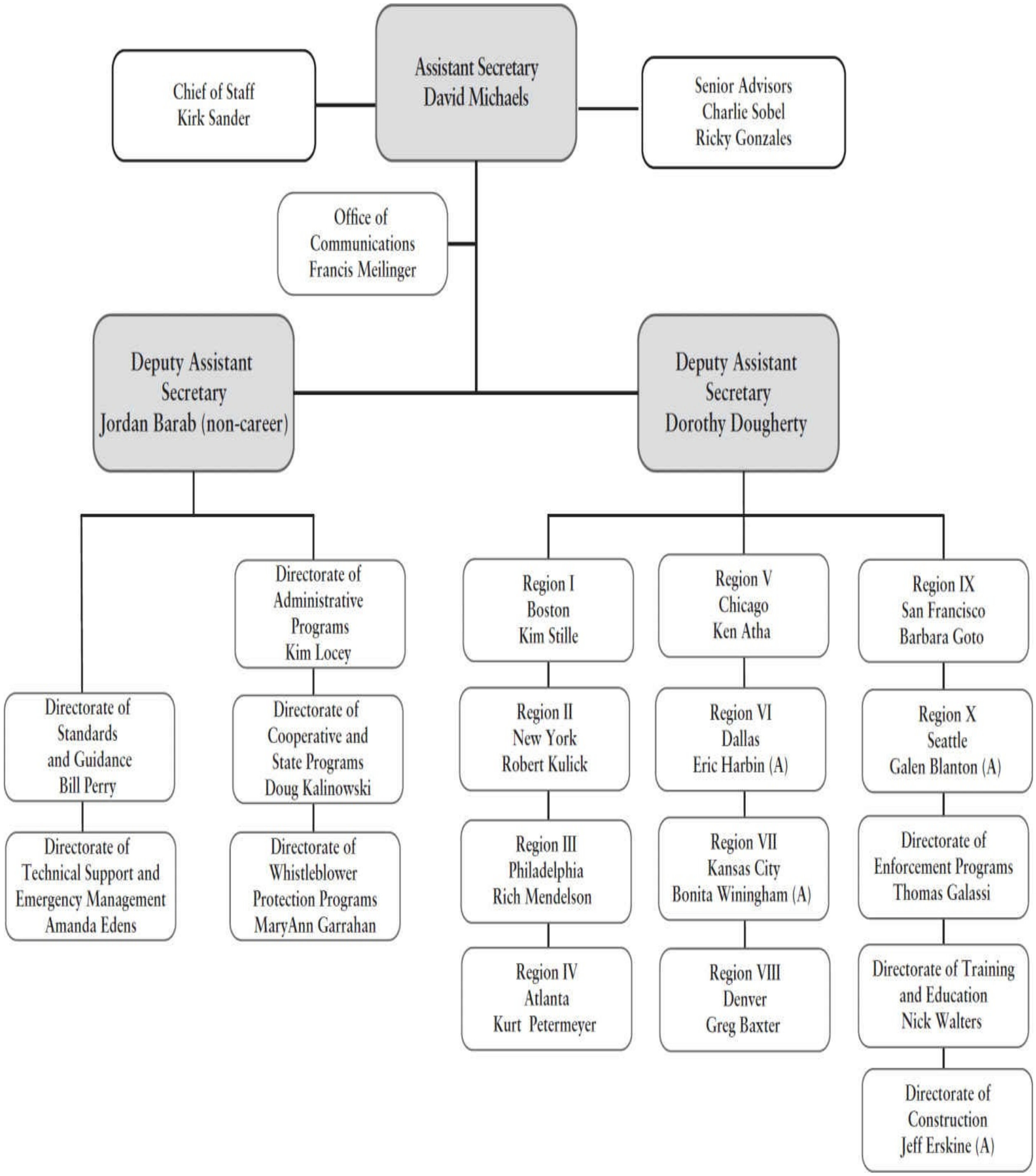

FIGURE 5-9 OSHA organizational chart, July 2016. (*Source: OSHA*)

OSHA RULEMAKING

Occupational Safety and Health Administration can initiate new standards on its own or if petitioned by other parties of relevance such as the Secretary of Health and Human Services (HHS), the *National Institute for Occupational Safety and*

Health (NIOSH), state and local governments, or any nationally recognized standards-producing organization. NIOSH is the U.S. federal agency responsible for conducting research and making recommendations for the prevention of work-related injury and illness. NIOSH is part of the Centers for Disease Control and Prevention (CDC) within the U.S. Department of Health and Human Services.

As the basic research arm of OSHA, NIOSH may also make recommendations to modify and/or promulgate standards. This agency conducts research and provides technical assistance to OSHA and industry on various safety and health hazards. During the course of its research, NIOSH may conduct workplace investigations, gather testimony from employers and employees, and require that employers measure and report employee exposure to potentially hazardous materials. NIOSH also may require employers to provide medical examinations and tests to determine the incidence of occupational illness among employees.

Osha Standards Affecting Aviation Operations: Examples

During OSHA’s near half century of existence, the agency has helped to save many thousands of lives and reduce occupational injury and illness rates by more than half. Although highlighting major developments would exceed the purview of this book, what follows is a short list of aviation-related examples of OSHA standards.

- *May 29, 1971*. Comprehensive standards were first adopted to provide a baseline for safety and health protection in occupational environments. Sample aviation operations that are regulated include aircraft manufacturing and assembly, hangar and other maintenance shop operations, painting and stripping, ramp and flight line operations, baggage handling, cleaning crew activities, and airport operations.
- *November 14, 1978*. The lead standard was introduced to protect workers from occupational exposure to lead, an element that is known to cause damage to human nervous, urinary, and reproductive systems. Aviation applications of this standard include battery maintenance and aircraft painting and stripping.
- *March 6, 1989*. The *hazardous waste operations and emergency response standard (HAZWOPER)* was promulgated to protect 1.75 million public and private sector workers exposed to toxic wastes from spills or at hazardous waste sites. Aircraft refueling, battery maintenance and disposal, deicing

operations, and manufacturing process discharges are covered by this standard.

- *December 6, 1991*. The *bloodborne pathogens standard* was introduced to prevent occupational exposure to AIDS, hepatitis B, and other infectious diseases. Flight attendants, safety investigators, baggage and cargo handlers, aircraft cleanup crew, and high-exposure-potential manufacturing and assembly jobs are covered by this standard. At the very least, employees in these positions require basic training on exposure prevention to blood and other potentially infectious material.
- *January 14, 1993*. The confined spaces (and permit-required confined spaces) standard was promulgated to prevent more than 50 deaths and more than 5,000 serious injuries annually. Employees who perform maintenance and fabrication work in elevators, bulkheads, and cargo holds are covered by this standard. Manufacturing facilities requiring employees to enter and work in spaces that have a limited means of entry, can engulf the employee, and are not designed for normal continuous work are covered by this standard.
- *November 14, 2000*. The ergonomics program standard was initiated to prevent a painful and debilitating category of musculoskeletal injuries that affect more than 102 million workers. These injuries develop from jobs requiring excessive repetitive motion and/or high forceful applications and/or awkward postures. Sample aviation jobs that could lead to repetitive-motion injuries are those performed by flight attendants, baggage handlers, data entry personnel, and aircraft assembly workers. Although this standard was repealed by Congress in March 2001, OSHA's "Effective Ergonomic Strategies for Success" program remains viable in today's workplace.
- In March 2012, the Occupational Safety and Health Administration (OSHA) revised its *Hazard Communication Standard* to align it with the United Nations Globally Harmonized System of Classification and Labelling of Chemicals (GHS), Revision 3. The revision to the Hazard Communication Standard (HCS) built on the existing standard, by requiring chemical manufacturers and importers to follow specific criteria when evaluating the hazardous chemicals and when communicating the hazards through labels and safety data sheets (SDSs).

For additional information on OSHA and its applicable regulations please refer to www.osha.gov.

THE ENVIRONMENTAL PROTECTION AGENCY (EPA)

Background

On December 2, 1970, the *Environmental Protection Agency (EPA)* was established in the Executive Branch of government as an independent agency. The EPA was created to enable coordinated and effective government action on behalf of the environment. The agency strives to abate and control pollution systematically by integrating a variety of research, monitoring, standard setting, and enforcement activities. To complement its other activities, EPA coordinates and supports research and antipollution activities by state and local governments, private and public groups, individuals, and educational institutions.

As stated on its Web site, the primary mission of the EPA is to protect human health and the environment. Going a bit deeper, the EPA's stated purpose is to ensure the following:

- All Americans are protected from significant risks to human health and the environment where they live, learn, and work.
- National efforts to reduce environmental risk are based on the best available scientific information.
- Federal laws protecting human health and the environment are enforced fairly and effectively.
- Environmental protection is an integral consideration in U.S. policies concerning natural resources, human health, economic growth, energy, transportation, agriculture, industry, and international trade, and these factors are similarly considered in establishing environmental policy.
- All parts of society—communities, individuals, businesses, and state, local, and tribal governments—have access to accurate information sufficient to effectively participate in managing human health and environmental risks.

EPA Organization and Major Offices

Office of the Administrator. This office provides overall direction and supervision of the Agency and reports directly to the President of the United States. The Office of the EPA Administrator includes Children's Health Protection, Civil Rights, Congressional and Intergovernmental Relations, Public Engagement and Environmental Education, and the Science Advisory Board among others.

OFFICE OF ADMINISTRATION AND RESOURCES MANAGEMENT. This office is responsible for national leadership, policy, and procedures governing administrative services and human resources.

OFFICE OF AIR AND RADIATION. This office develops national programs, policies, and regulations for controlling air pollution and radiation exposure. This office is responsible for administering the Clean Air Act, the Atomic Energy Act, and other applicable environmental laws.

OFFICE OF CHEMICAL SAFETY AND POLLUTION PREVENTION. This office is responsible for protecting the environment from potential risks from pesticides, as well as toxic chemicals, and also works to prevent pollution before it begins. It implements and monitors regulatory activities relating to the following laws:

- Federal Insecticide, Fungicide and Rodenticide Act
- Federal Food, Drug and Cosmetic Act
- Toxic Substances Control Act
- Pollution Prevention Act

OFFICE OF ENFORCEMENT AND COMPLIANCE ASSURANCE. This office is the regulatory enforcement wing of the EPA and advises the EPA Administrator on matters concerning administrative, civil, and criminal enforcement; environmental-equity efforts; and compliance monitoring and assurance activities. There is also a strong focus on environmental justice by protecting vulnerable communities.

OFFICE OF ENVIRONMENTAL INFORMATION. Headed by the Chief Information Officer, this office manages the life cycle of information to support EPA's mission of protecting human health and the environment. It identifies and implements information technology and information management solutions; ensures the quality of EPA's information and the efficiency and reliability of EPA's technology, data collection, and exchange efforts; and access services.

OFFICE OF RESEARCH AND DEVELOPMENT. Science at EPA provides the foundation for credible decision making to safeguard human health and ecosystems from environmental pollutants. This office is the scientific research arm of EPA, whose leading-edge research helps provide the solid underpinning of science and technology for the Agency. The work at EPA research and development laboratories, research centers, and offices across the country helps

improve the quality of air, water, soil, and the way resources are utilized**.**

OFFICE OF WATER. Office of Water ensures drinking water is safe and restores and maintains oceans, watersheds, and their aquatic ecosystems to protect human health, support economic and recreational activities, and provide healthy habitat for fish, plants, and wildlife.

There are 10 EPA *Regional Offices* (States Covered) and Office Locations:

- Region 1 (CT, ME, MA, NH, RI, VT), Boston
- Region 2 (NJ, NY, PR, and VI), New York
- Region 3 (DE, MD, PA, VA, WV, DC), Philadelphia
- Region 4 (AL, FL, GA, KY, MS, NC, SC, TN), Atlanta
- Region 5 (IL, IN, MI, MN, OH, WI), Chicago
- Region 6 (AR, LA, NM, OK, TX), Dallas
- Region 7 (IA, KS, MO, NE), Kansas City
- Region 8 (CO, MT, ND, SD, UT, WY), Denver
- Region 9 (AZ, CA, HI, NV, and U.S. Pacific Islands), San Francisco
- Region 10 (AK, ID, OR, WA), Seattle

EPA RULEMAKING

The EPA rulemaking process is similar to the one described under OSHA rulemaking. Initially, an authorized agency such as the EPA decides that a regulation may be needed. The Agency then researches the need for the regulation and proposes it, if needed. The proposal is listed in the *Federal Register*, and comments are invited from members of the public. The Agency reviews all comments, makes changes where appropriate, and issues a final rule.

During the standards development process, all information regarding the original proposal, requests for public comment, notices about meetings (time and place) for public discussions, and the text of the final regulation is published in the Federal Register. Biannually, the Agency publishes a report that documents its efforts on all the regulations it is working on or has recently finished. Environmental regulations appear in Title 40 of the U.S. Code of Federal Regulations (CFR).

MAJOR ENVIRONMENTAL LAWS AFFECTING AVIATION

Although highlighting major developments would exceed the purview of this book, what follows is an aviation-related subset of major EPA laws and regulations.

NATIONAL ENVIRONMENTAL POLICY ACT (NEPA). The *National Environmental Policy Act (NEPA)* was passed in 1969 and was significant in that it was among the first laws to establish a broad national framework for protecting the environment. NEPA's fundamental policy was to make certain that all branches of government gave careful consideration to the environment before any major federal undertaking such as airports, military complexes, highways, parkland purchases, and other federal activities that are proposed. The Act requires *Environmental Assessments* (EAs) and *Environmental Impact Statements* (EISs) on the impact of all major undertakings and alternative courses of action on the environment.

CLEAN AIR ACT (CAA). The *Clean Air Act (CAA)* was passed in 1970 and regulates air emissions from area, stationary, and mobile sources. In recent years, global climate change has become a significant issue, and aircraft emissions have become important to the environmental movement. Aircraft are producers of "greenhouse gases," that is, compounds that trap the Sun's heat within the Earth's climate. The EPA has the authority to regulate greenhouse gas emissions under the Clean Air Act, or Congress could address aviation legislation through modification of cap-and-trade or carbon tax proposals. Foreign countries, and, particularly, the European Union, have attempted to control aviation emissions as well. In August 2016, the EPA proposed to find whether greenhouse gas emissions from certain classes of engines used in aircraft contribute to the air pollution that causes climate change endangering public health and welfare. In this era of "global warming," aviation greenhouse gas emissions will remain an issue for the foreseeable future.

CLEAN WATER ACT (CWA). The *Clean Water Act (CWA)*, in its original and modified forms, gave the EPA the authority to implement pollution control programs such as setting wastewater standards for industry and water quality standards for surface waters. Under the Act, it was unlawful for anyone to discharge pollutants into navigable waters, unless a permit was obtained. It also established grants to fund the construction of sewage treatment plants. Such requirements require significant attention by airport managers, particularly with regards to the proper collection and treatment of used aircraft deicing and anti-icing fluid.

RESOURCE CONSERVATION AND RECOVERY ACT (RCRA). This Act by far is the most far reaching of all EPA laws and is of major importance to the aviation industry. By virtue of the *Resource Conservation and Recovery Act (RCRA)* of 1976, the EPA has the authority to control hazardous waste from "cradle to grave." This cradle-to-grave approach governs all phases of the waste from generation and transportation through treatment, storage, and disposal. Hazardous wastes can be solids, liquids, or contained gaseous materials that could pollute the environment. Sources of hazardous wastes in aviation operations include the following:

- Painting, degreasing, and cleaning of aircraft generate paint wastes, phenols, organic solvents, acids, and alkalis.
- Plating, stripping, rust prevention, and stain removal generate cyanides chromium, and other toxic metals.
- Spills and leaks from fuel systems and storage tanks generate fuels, oils, and grease.
- Spent or leaking batteries from aircraft, ATC tower backup, and other power supply sources generate toxic (lead, lithium, nickel, and cadmium) and reactive (acid) wastes.
- Miscellaneous wastes include glycol used for deicing and other detergents.

RCRA focuses only on active and future facilities and does not address abandoned or historical sites. Historical and abandoned sites are addressed by CERCLA.

COMPREHENSIVE ENVIRONMENTAL RESPONSE, COMPENSATION, AND LIABILITY ACT (CERCLA) or "SUPERFUND". The *Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)* or *"Superfund"* provided broad federal powers to respond directly to releases or potential releases of hazardous chemicals that posed risks to public health or the environment. The Act established requirements concerning closed and abandoned hazardous waste sites and provided for liability of individuals responsible for contaminating sites with hazardous wastes.

The Act also gave EPA the power to seek out the parties that were responsible for the pollution and force them to clean up. Finally, this Act created a tax on the chemical and petroleum industries to generate funds to provide for cleanup when a responsible party could not be identified. Hence this Act is also known as the Superfund. Sample applications of this law would be to aircraft burial (retirement) sites and old (discontinued) fuel dumping/storage facilities

burial (retirement) sites and old (discontinued) fuel dumping/storage facilities involving underground fuel storage.

Superfund Amendments and Reauthorization Act (SARA). As a result of the complex administering requirements of Superfund, changes and additions were made to the program which resulted in the enactment of the *Superfund Amendments and Reauthorization Act (SARA)* of 1986. Several site-specific amendments, definitions, clarifications, and technical requirements were added to the legislation, including additional enforcement authorities. The size of the fund was increased to $8.5 billion to pay for cleanup activities around the country. Some of the other salient features of the Act were that it required states to get involved in all phases of the Superfund program, stressed human health concerns posed by hazardous waste sites, and encouraged greater community involvement in the site cleanup decision-making process.

Oil Pollution Act (OPA). The *Oil Pollution Act (OPA)* of 1990 was adopted after the highly publicized Exxon Valdez oil spill in 1989, where up to 38 million U.S. gallons of crude oil were spilled in Alaska when an oil tanker struck a reef. The act was passed to strengthen EPA’s ability to prevent and respond to catastrophic oil spills. A trust fund, financed by a tax on oil, was established to clean up spills when the responsible party was unable or unwilling to do so. Oil storage facilities and transport vessel operators are required to submit detailed plans to the federal government on how they will manage large-scale inadvertent discharges. The EPA also has specific requirements for aboveground storage facilities. This regulation applies to aviation fueling and storage operations. The EPA has jurisdiction for inland oil spills, and the U.S. Coast Guard responds in coastal waters.

The Oil Pollution Act became very important to the U.S. government in the wake of the British Petroleum Oil Rig disaster that occurred in the Gulf of Mexico near the mouth of the Mississippi River in Louisiana in 2010. The Oil Pollution Act of 1990 provides that the responsible party must pay for oil spill damages, and British Petroleum agreed to establish a $20 billion trust fund to pay for these damages. The cataclysmic nature of the BP oil spill damage to the Gulf Coast region will ensure that public scrutiny is applied to any oil spills, including those related to aviation, for years to come.

Noise Control Act (NCA). In the past, the EPA coordinated all federal noise control activities through its Office of *Noise Abatement and Control*. However, in 1981, the Administration at that time concluded that noise issues were best handled at the State or local government level. This area is improving through

effective airport departure noise abatement procedures that provide guidance to pilots on flight profiles and operating processes to minimize the amount of noise that is created during approach and departure.

Regarding future noise reduction, in February 2013, the ICAO's Committee on Aviation Environmental Protection (CAEP) agreed to a new global noise reduction standard. The FAA participates in the ICAO CAEP meetings and supports this new standard. The most beneficial area of future noise reduction is future engine technology development to reduce source noise. NextGen ATC procedures will also improve aircraft noise pollution in the years to come.

The impact of aircraft noise can be extremely invasive in everyday life and can result in disrupted sleep cycles, productivity, and safety problems associated with fatigue. Figure 5-10 shows a Boeing 747-400 on approach to a runway near a residential area.

FIGURE 5-10 Noise pollution can have an enormous impact on residents. (*Source: Wikimedia Commons*)

For additional information on EPA and its applicable regulations please refer to www.epa.gov.

ASRS EXAMPLE

Even though the FAA aims to create regulations that will improve working conditions for everyone working in the aviation field, sometimes the new rules cause controversy. Below is a submission to the ASRS from a pilot who thinks the implementation of FAR 117 has done more harm than good in its attempt to help manage fatigue.

PILOT WARNS ABOUT FATIGUE

> *On departure, I missed a couple ATC radio calls. They were normal clearance calls and not urgent, but I just plain missed the calls. I also noticed that ATC communications with multiple instructions (heading, altitude, frequency, etc.) were difficult to mentally process and read back. I feel I was suffering the effect of accumulated fatigue. When we got to cruise, I tried to move around and get the "blood flowing," had a bite to eat and was able to complete my duties as pilot not flying for the duration of the flight. I noticed on the radio that many other "company" call signs were also completely missing radio calls and miss-repeating clearances. These were call signs that I could distinctly hear and all of them were having difficulty with ATC of one kind or another and making mistakes. As the night progressed, I heard at least two times of ATC trying to contact "company" flights multiple times with no response.*
>
> *The Captain and I discussed the issues at length during cruise. Both of us admitted to being more generally tired (on and off duty) than ever before in our careers. In all of our conversations with other pilots we are hearing the same story of being "beat," "exhausted," "tired,' 'worn out" and even the dreaded "fatigued." The general consensus is that our work schedules have gotten so bad that we are unable to rest and recover when home or off duty. It is common to hear pilots complain that it feels like they are never home any more.*
>
> *First let me say that I am no slouch. I believe in doing an honest day's work for an honest day's pay and have worked hard all my life. Since the advent of FAR 117 and Company schedule changes, the pairings and monthly schedules out of my domicile have progressively gotten worse. These abuses of an airline-favorable regulation (117) and the perceived dumping of a lot of "bad" flying on my domicile appears to be taking a toll after 5 months of accumulation. Myself and all pilots I speak with agree that an accident is not a matter of "if," but of "when." From what I heard on the radio on this night, the "when" may be soon. For the first time in my career, I legitimately know what fatigue feels like. For the first time in my career, I am legitimately afraid of putting my loved ones on our planes. FAR 117 needs to be reviewed now that we are six months in. From all pilots' point of view, it has made things far worse than they have ever been before. We are ALL more tired and burned out (including our off-duty lives) than ever before. Company schedule creation policy needs to be reviewed. Domicile schedules have continued to erode over the last several years. It is finally taking its toll and starting to catch up with all of us.*
>
> *Company crew accommodations policy needs to be reviewed. Pilots generally agree that the quality of crew accommodations has eroded in line with the pairings. It is getting more difficult to get a good rest and almost as importantly a good healthy meal at many of the hotels in which we are now being placed and this is contributing to overall fatigue. Is it going to take an accident to fix these issues?*

Discussion Question for the reader: what action should the FAA and airlines take, if any, based on this report?

CONCLUSION

The role of government may seem to be a tedious subject to most aviation operational personnel, but it is very important to a serious student of commercial aviation safety. To ensure the safety of our skies it takes continuous dedicated effort by many people across a large number of organizations. The task alone is too daunting to be handled solely by one interest group. Each group involved in the process has its own structure and rulemaking process to meet the needs of issues they are addressing. Due to the complexity of the subject matter, challenges do arise when collaborating on rules and regulations.

Commercial aviation safety has been greatly improved due to the dedicated work of government regulating agencies that make safety procedures mandatory. Figure 5-11 shows the very first official flight of the U.S. Airmail Service in 1918. One cannot help but wonder if these people had any idea of the huge aviation industry that would develop in the years to come. Over the past century since the picture was taken, government regulators across the globe have weaved a complex web of regulations which, when properly followed, are extremely critical to the safe operation of commercial aircraft.

FIGURE 5-11 The first U.S. Air Mail flight. (*Source: Wikimedia Commons*)

Perhaps the most significant take-away from this chapter is that government rulemaking and policy must be based on science, not emotion. When we approach rulemaking with an emotional lens, it often detracts from rules that may have the largest positive impact. The aviation industry always strives to operate in the safest possible manner, and the role of government is a critical part of this effort.

The example of the development of the ATP-CTP licensing rules provides ample exposure to the government rulemaking process. The role of government is important, but it is only one weapon in our continuing mission to ensure the safety of commercial aviation operations.

KEY TERMS

Air Navigation Capacity and Efficiency
Air Traffic Organization (ATO)
Air Transport Pilot Certification Training Program (ATP-CTP)
Aviation Rulemaking Advisory Committee (ARAC)

Aviation Rulemaking Advisory Committee (ARAC)
Aviation Safety (AVS)
Blood Priority
Bloodborne Pathogens Standard
Chicago Convention
Clean Air Act (CAA)
Clean Water Act (CWA)
Commercial Space Transportation
Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or Superfund
Economic Development of Air Transport
Environmental Protection
Environmental Protection Agency (EPA)
FAR Part 117
FAR Part 121
FAR Part 135
Fatigue
Federal Aviation Administration (FAA)
Flight Standards District Offices (FSDOs)
Flight Standards Service
Hazard Communication Standard
Hazardous Waste Operations and Emergency Response Standard (HAZWOPER)
International Civil Aviation Organization (ICAO)
National Environmental Policy Act (NEPA)
National Institute for Occupational Safety and Health (NIOSH)
Next Generation Air Transportation System (NextGen)
Noise Abatement and Control
Occupational Safety and Health Administration Act of 1970
Oil Pollution Act (OPA)
Procedures for Air Navigation Services (PANS)
Regional Supplementary Procedures (SUPPs)
Research, Engineering, and Development
Resource Conservation and Recovery Act (RCRA)
Security and Facilitation
Standards and Recommended Practices (SARPs)
Superfund Amendments and Reauthorization Act (SARA)

REVIEW QUESTIONS

1. List three strategic objectives of ICAO and discuss their importance in international aviation.
2. State the purpose and name one result of the Chicago Convention of 1944.
3. Discuss the ICAO Rulemaking Process including the role of SARPs, PANS, and SUPPs.
4. Why does it take about 2 years for new guidance to be formulated through the ICAO Preliminary Review by the ANC?
5. List three major functions of the FAA and discuss some of the activities that support these functions.
6. How has inspector workload been affected since airline deregulation? Why has it been difficult attracting inspectors to major metropolitan areas?
7. Explain the evolution of the EPA.
8. Highlight the major environmental acts relevant to aviation, giving examples of each.
9. Explain the evolution of OSHA.
10. Provide examples of how OSHA and the EPA impact aviation.

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International Civil Aviation Organization: http://www.icao.int

Occupational Safety and Health Administration: http://www.osha.gov

CHAPTER SIX

REACTIVE SAFETY

LEARNING OBJECTIVES

After completing this chapter, you should be able to

- Understand why the accident investigation process is important.
- Distinguish between findings, causes, and recommendations.
- Explain the international accident investigation process.
- Discuss ICAO's role in international accidents.
- Describe the purpose of the National Transportation Safety Board (NTSB) and its organizational structure.
- List the types of aviation accidents investigated by the NTSB.
- Explain the steps involved in investigating a major commercial aviation accident.
- Discuss the composition, function, and working of the go-team, the party system, and the board of inquiry as they relate to accident investigation.
- Summarize the responsibilities of the FAA during an investigation.

- Discuss the NTSB's most wanted aviation safety improvements.

INTRODUCTION

It can often be tedious to learn about the policy making side and the structure of organizations involved in creating regulations for aviation safety. However, it is of course an inherent component of understanding how the industry operates. As we saw in the last chapter, unfortunately many of the laws we have today are "written in blood," as they have emerged from the loss of life and not necessarily from proactively thinking about the flaws in the aviation safety system. In this chapter, we switch gears from discussing the bureaucracy of regulating safety to the investigation of a breakdown in safety.

Upon news of a crash, people immediately start mobilizing to prepare for the accident investigation. This includes deploying teams to the crash site, collecting data at the scene, and finally writing a report to share recommendations on how to prevent the accident from happening again. The contents of this chapter focus on the details associated with each phase of an investigation to provide a big-picture idea of what the process looks like. We wrap up the chapter with a case study of the Spanair Flight 5022 accident to show how everything we learned can be extended to real-life situations.

As you will see, aviation accidents require very detailed and nuanced investigations by hundreds of experts in order to determine not only the apparent causal factors but also the underlying conditions that helped the causal factors lead to the accident. These investigations help us craft recommendations for creating a safer aviation community.

WHY INVESTIGATE?

We investigate accidents to prevent future ones. The future accidents that are to be prevented do not necessarily have to look like the one that is being investigated. The major objective for investigating accidents is identifying hazards, and those hazards discovered need to be addressed through *safety risk management*, whether they actually were important to the accident in question or not, since they could create future accidents.

Proactively finding, evaluating, and controlling safety-related hazards obviously facilitate accident prevention. But what do safety professionals consider a hazard? A hazard is any internal or external condition, event, or circumstance that can cause injury or damage; a hazard affects humans and other

system functionalities to cause failures. Figure 6-1 shows one of many different ways an accident scene may look like from the various hazards that exist today. Hazards must be identified, analyzed for risks, assessed, prioritized, and documented for decision-making purposes. Constantly going through this routine enables aviation safety professionals to determine the current safety status of an aviation organization.

FIGURE 6-1 We must investigate all accidents to identify hazards that can jeopardize safety. (*Source: NTSB*)

During an accident investigation, it is important to note that there is a significant difference between an engineering technical investigation and a human-performance investigation. Many accidents are the result of improper human performance. In the aviation system, the human element is the most flexible, adaptable, and valuable component. Human-performance investigations help us attempt to explain how and why humans performed the way they did in a given circumstance. As a result, we can formulate and revise regulations, rules, and training to help people perform better.

In contrast, technical investigations provide engineering assessments and evaluations of the technical aspects of an accident sequence. It allows for establishing facts, drawing conclusions, and determining causes for how certain components performed. Technical investigations and human factors use

components performed. Technical investigations and human factors use difference resources when examining causes. Although they are different, their findings complement each other for painting the whole picture of why the accident happened. Often both types of investigations run simultaneously and even interface with each other, particularly when examining how humans interact with aircraft systems and components, such as flight deck automation.

FINDINGS

In accident investigations, *findings* are the factors that contributed significantly to the accident. An exact definition of findings seems to be slightly nebulous, as ICAO, FAA, and NTSB do not clearly define them. Due to this, the *International Society of Air Safety Investigators* has recommended that ICAO define findings as “all significant conditions and events, causal and non-causal, found in an investigation.”

The U.S. Air Force does define findings, calling them the conclusions of the investigating body, which are “based on the weight of evidence, the investigators’ professional knowledge and their best judgment.” As such, findings are statements of significant events or conditions leading to the accident. They are arranged in the order in which they occurred. Developing findings is a very useful way to account for the investigator’s conclusions from an accident. It is important to note that findings are not necessarily causal factors in an accident. However, from the findings, the investigator can choose which items were actual causes.

CAUSES

A *cause* is a finding which singly or in combination with other causes, resulted in the damage or injury that occurred. A cause is also deficiency which if corrected, eliminated, or avoided, would likely have prevented or mitigated the damage or injuries associated with an accident or incident.

Some investigators ask themselves three questions to test if a finding is indeed causal. This is often called the *three-step causation test*. If all three answers to the questions are “yes,” then the finding likely helped cause the event. The three questions are as follows:

- Did the finding start or sustain the accident sequence?
- If the finding had not existed, would the accident likely have been prevented?
- If the finding is related to human performance, is it reasonable to expect that a

human would have behaved otherwise?

For example, imagine an accident where a commercial aircraft skids off the end of a runway during landing following a snowstorm, where the tower had relayed to the crew that the runway braking condition was good, as told to them by the airfield manager. During the investigation a finding is established that the airfield management failed to accurately report the braking condition of the runway, given that the condition was actually poor rather than good. Is the finding a cause? Let us apply the three-question test:

- Did the inaccurate report start or sustain the accident sequence? Yes.
- If the report had not been inaccurate, would the accident likely have been prevented? Yes. Let us say that the deceleration performance analysis indicates so.
- Is it reasonable to expect the correct reading of the braking condition? Yes.

According to the three-question test, the finding is likely one of the causes of the accident.

Continuing with our example, let us say that another finding was, “the pilots did not apply maximum braking to decelerate the aircraft during the landing because of an unknown valve problem in the anti-skid braking system.” Is the finding one of the causes of the accident? Let us apply the three-question test:

- Did not applying maximum braking start or sustain the accident sequence? Yes.
- Would applying maximum braking have likely prevented the accident? Yes. Let us say that the deceleration performance analysis indicates so.
- Is it reasonable to expect the pilots to have applied maximum braking in the situation? No. They could not have anticipated the failure in the braking system.

Because the last test was negative, the finding is likely not one of the causes of the accident. At this point the reader may be confused. After all, the lack of maximum braking certainly contributed to the accident. How can we say it was not a cause? The three-question test is telling us that the finding is not causal, but yet we know the lack of sufficient braking was important.

Usually this is an indication that the finding needs to be rewritten. A seasoned investigator facing this situation will dig deeper, searching to answer why the

maximum braking did not occur, then rewrite the finding, and then perform the test again. In the example, let us say that a technical analysis of the braking system was requested at the NTSB laboratory, as shown in Figure 6-2.

FIGURE 6-2 Examining a component using a microscope in a lab. (*Source: NTSB*)

Continuing with our example, imagine that the laboratory report of the braking system shows that a hydraulic fluid valve failed upon initial brake application during landing, and an investigation of the maintenance process shows that an inspection of the hydraulic valves in the braking system was documented but not actually accomplished 1 week before the accident.

The investigator may now wisely decide to rewrite the original finding since numerous other factors have been uncovered. The investigator has established that insufficient braking was achieved as a result of low hydraulic pressure in the brake system due to a faulty valve. Furthermore, the investigator has uncovered that the faulty valve should have been caught during an inspection but was not, because of an improper shift change between aviation maintenance technicians performing the inspection since no procedure exists for performing the shift change.

The investigator will probably decide to divide that very long finding into a

series of smaller findings, and one of them may be, “no established procedure exists to ensure maintenance task completion during shift changes.” Is the finding one of the causes of the accident? Let us apply the three-question test:

- Did not having a procedure start or sustain the accident sequence? Yes.
- Would having a proper procedure have likely prevented the accident? Yes.
- Is it reasonable to expect that the maintenance organization of the airline should have such a procedure? Yes.

Congratulations! We have now determined another cause of the accident. Notice that removing either of the two stated causes would have prevented the accident. Furthermore, we have shown just how complex it can be to determine causes. A less sophisticated approach to accident investigation would have simply stated the case as, “the pilots didn’t stop the aircraft before the end of the runway.” But the reality is that the combination of the faulty braking action report and the mechanical issue with the brakes may have made stopping the aircraft in the available runway nearly impossible. Furthermore, by rewriting the finding we have made it much easier to craft a recommendation that addresses the finding.

Accident theory has evolved in sophistication through the years. For a long time there was a belief that a single cause produced any given accident. Such a *monocausal* approach to accident investigation was problematic because invariably there were some findings left over after the single cause was assigned that could also be classified as a cause. Other findings would have had to occur in order for the accident to unfold as it did. Referring back to our example of the aircraft skidding off the runway, we determined two causes, and there were probably more. If we only established the cause as one of the two, we would have only partially solved the puzzle.

Eventually, safety professionals accepted the concept of *multicausality*, whereby several causes are perceived as producing any given crash. It was not until 1994 that the NTSB changed their format to begin listing multiple probable causes. Even then, some investigators clung to the belief that some causes were more important than others, labeling them as the *primary*, *trigger*, or *main* cause. Again, this was a problematic perspective because each cause, by definition, could have prevented the accident, and therefore removing it from the accident sequence could have prevented the event. Today, during the process of cause determination, we should keep the following items in mind:

- There is not a single cause for an aircraft accident. Accidents are always

multicausal.

- All causes should be listed chronologically. Listing them in a different order can imply that some causes are more important than others.

Once the causes have been established, investigators can use them to craft the recommendations.

RECOMMENDATIONS

The previous discussion of findings, some of which are causal, is very important. How we write up those causal findings is extremely critical. Why? Because recommendations are crafted to address those causal findings, so if we do not properly write those findings, we can damage the accuracy of the recommendation.

Recommendations are the single most important takeaway from the accident investigation since the whole purpose of investigating the accident is to prevent future accidents. Investigators want to eliminate other accidents from happening with the same causes, and therefore, work diligently to identify the deficiencies that need correction. Recommendations are essentially suggestions about how to make air transportation safer. Generally, they are as nonspecific as possible to prove maximum flexibility for solving problems.

One persistent problem that arises from creating recommendations is the challenge of convincing regulators to implement change. Developing and putting new regulations into practice can be resource intensive. Doing so requires time, money, and careful planning; however, regulators seem to be most sensitive to the financial costs of safety. There is sometimes difficulty in proving to regulators that they should invest in a safety measure that does not exist, even though it could greatly enhance safety for the aviation community; this is because regulators must themselves justify any given expense as part of the many similar initiatives that are constantly under consideration for funding from a limited budget.

INTERNATIONAL ACCIDENT INVESTIGATION

OVERVIEW

As introduced in Chapter 5, ICAO has played a major part in international aviation matters since its establishment in 1944. Commercial aviation safety has truly become a worldwide concern in the modern era of jet airline transportation,

and the *ICAO Chicago Convention* provides for international cooperation in accident investigations in two documents: Article 26 of the Convention and in its Annex 13 entitled, *Aircraft Accident and Incident Investigation*. This section sets forth ICAO's role in this process and explains how the aircraft accident investigation process is handled on a worldwide basis.

ICAO's Role

What if a commercial aircraft manufactured in the United States but flying for a European airline crashes in Argentina? Who should be responsible for investigating the accident? The international process for aircraft accident investigation is set forth in Annex 13 of the Chicago Convention. This document provides the following principles:

- The ultimate objective of accident investigation is prevention.
- Responsibility for an investigation belongs to the member State in which the accident or incident occurred (State of Occurrence).
- All ICAO States that may be involved must be promptly notified of the accident or incident occurrence.
- Other member States may participate in an investigation based upon their relationship to the accident, such as the State where:
  - The aircraft is registered.
  - The operator is based.
  - The aircraft was designed and manufactured.
- States of Registry, Operator, Design, and Manufacture are entitled to appoint an *accredited representative* of that State to take part in the investigation.
- Experts and advisors may also be appointed to assist accredited representatives. The ICAO member State conducting the investigation may call on the best technical expertise available from any source to assist with the investigation.
- The investigation process includes gathering, recording, and analysis of all relevant information; determination of the causes of the accident; formulating appropriate safety recommendations; and completion of the final report.

Regional and National Authorities

The following are the primary international authorities empowered to investigate aircraft accidents in their state or region:

- Australia—Australian Transport Safety Bureau
- Canada—Transportation Safety Board of Canada (BST/TSB)
- France—Bureau d’Enquêtes et d’Analyses (BEA) pour la Sécurité de l’Aviation civil
- Mexico—Secretariat of Communications and Transportation (SCT)
- Russia (Commonwealth of Independent States, Former USSR area)—Interstate Aviation Committee (MAK)
- United Kingdom—Air Accidents Investigation Branch (AAIB) of the U.K. Department for Transport
- United States—National Transportation Safety Board (NTSB)

RECENT MAJOR INTERNATIONAL INVESTIGATION

An example of a relatively recent and high-profile international investigation comes in the form of Air France Flight 447. On June 1, 2009, an Airbus A330-200 aircraft en route from Rio de Janeiro to Paris (Charles de Gaulle Airport) and operated as Air France Flight 447 crashed in the Atlantic Ocean causing 228 fatalities. This has been described as the worst accident in French aviation history by the BEA, the agency that investigated the accident under Annex 13 of the ICAO Convention. The NTSB assigned an “accredited representative” to assist the BEA in this investigation.

The outpouring of effort from the international community to investigate the Air France Flight 447 accidents shows how commercial aviation safety remains a top priority of ICAO and its member States. The 37th Assembly of ICAO strongly endorsed the sharing of safety information, and the United States offered its leadership and support by signing a precedent-setting agreement with ICAO, the European Union, and the International Air Transport Association (IATA) to facilitate such sharing using modern Safety Management Systems (SMS) concepts. To showcase how accident investigations occur within a single nation state we will next feature the United States and explore the NTSB’s organization and accident investigation process.

NATIONAL TRANSPORTATION SAFETY BOARD

The *National Transportation Safety Board (NTSB)*, as pictured in action in Figure 6-3, is an independent agency of the U.S. government that determines the

probable cause of transportation accidents and promotes transportation safety through the recommendation process. It is a relatively small agency of about 400 personnel who address multiple modes of transportation, not just aviation. The NTSB also conducts safety studies, evaluates the effectiveness of transportation safety programs of other government agencies, and reviews appeals of adverse actions by the FAA and U.S. Department of Transportation (DOT) involving pilot and mariner certificates and licenses.

FIGURE 6-3 NTSB personnel investigating the UPS Flight 1354 accident. (*Source: NTSB*)

To help prevent accidents, the NTSB develops and issues safety recommendations to other government agencies, industry, and organizations that are in a position to improve transportation safety. These recommendations are always based on the NTSB's investigations and studies and are the focal point of its efforts to improve safety in U.S. transportation systems.

In 1967, Congress consolidated all transportation agencies into a new DOT and established the National Transportation Safety Board. With the passage of the *Independent Safety Board Act of 1974*, Congress made the NTSB completely independent outside the DOT because "no Federal agency can properly perform such investigatory functions unless it is totally separate and independent from

any other … agency of the United States." Since the DOT is charged with both the regulation and the promotion of transportation in the United States, and accidents may suggest deficiencies in the system, the NTSB's independence is necessary for objective oversight.

NTSB Mission

The NTSB states its mission is to promote transportation safety by:

- Maintaining its congressionally mandated independence and objectivity.
- Conducting objective, precise accident investigations and safety studies.
- Performing fair and objective airman and mariner certification appeals.
- Advocating and promoting safety recommendations.
- Assisting victims of transportation accidents and their families through Transportation Disaster Assistance (TDA) (www.ntsb.gov).

In creating the NTSB, Congress envisioned that a single agency could develop a higher level of safety than the individual modal agencies working separately. In its major role, the NTSB's mission is to determine the probable cause of transportation accidents and to formulate safety recommendations to improve transportation safety.

It is important to note that the NTSB has no authority to regulate, fund, or be directly involved in the operation of any mode of transportation. Therefore, it has the ability to oversee the entire U.S. transportation system, conduct investigations, make recommendations from a totally objective viewpoint, and make recommendations for needed safety improvements. Its effectiveness depends on an ability to make timely and accurate determinations of the cause of accidents, along with comprehensive and well-considered safety recommendations. The most visible portion of the NTSB involves major accident investigations. Under its accident selection criteria, the NTSB's investigative response depends primarily on:

- The need for independent investigative oversight to ensure public confidence in the transportation system.
- The need to concentrate on the most significant and life-threatening safety issues.
- The need to maintain a database so that trends can be identified and projected.

The National Transportation Safety Board investigations include the participation of non governmental external parties, such as manufacturers, operators, and employee unions. Within the transportation network, each government organization has been established to fulfill a unique role. As the only federal agency whose sole purpose is promoting transportation safety, the NTSB conducts detailed, open, and thorough accident investigations that often uncover significant system-wide problems that need to be corrected to prevent future similar accidents.

Under the Independent Safety Board Act of 1974, the NTSB investigates hundreds of accidents annually, including the following within the aviation mode of transportation:

- All accidents involving 49 Code of Federal Regulations (CFR) Parts 121 and 135 air carriers.
- Accidents involving public (i.e., government) aircraft (except military accidents).
- Foreign aircraft accidents involving U.S. airlines and/or U.S.-manufactured transport aircraft or major components.
- Accidents involving air traffic control, training, midair collisions, newly certified aircraft/engines, and in-flight fire or breakup.
- General aviation accidents, some of which are delegated to the Federal Aviation Administration (FAA) for fact finding (it is important to note, however, that probable-cause determinations are never delegated).
- Certain drone accidents, as explained in the July 2016 NTSB Advisory to Operators of Civil Unmanned Aircraft Systems in the United States.

In addition, based on the agency's mandate under Annex 13 to the Chicago Convention and related international agreements, the NTSB participates in some investigations of commercial aviation accidents throughout the world. The NTSB enjoys a worldwide reputation. The major share of the NTSB's air safety recommendations are directed to the FAA. These recommendations have resulted in a wide range of safety improvements in areas such as pilot training, aircraft maintenance and design, air traffic control procedures, and survival equipment requirements.

The NTSB is also empowered to conduct special studies of transportation problems. A special study allows the NTSB to break away from the mold of the single accident investigation to examine a safety problem from a broader perspective. In the past, for example, the NTSB has conducted special studies on

weather, how well aircraft withstand impact forces (crashworthiness), in-flight collisions, and commuter airlines. As of 2015, the NTSB has investigated over 140,000 aviation incidents and several thousand surface transportation incidents. Since its establishment, NTSB has issued more than 14,000 safety recommendations to more than 2,500 recipients.

NTSB ORGANIZATION

As provided on its Web site, there are three levels to the NTSB organization chart, which is provided in Figure 6-4. For the latest information, please visit www.ntsb.gov.

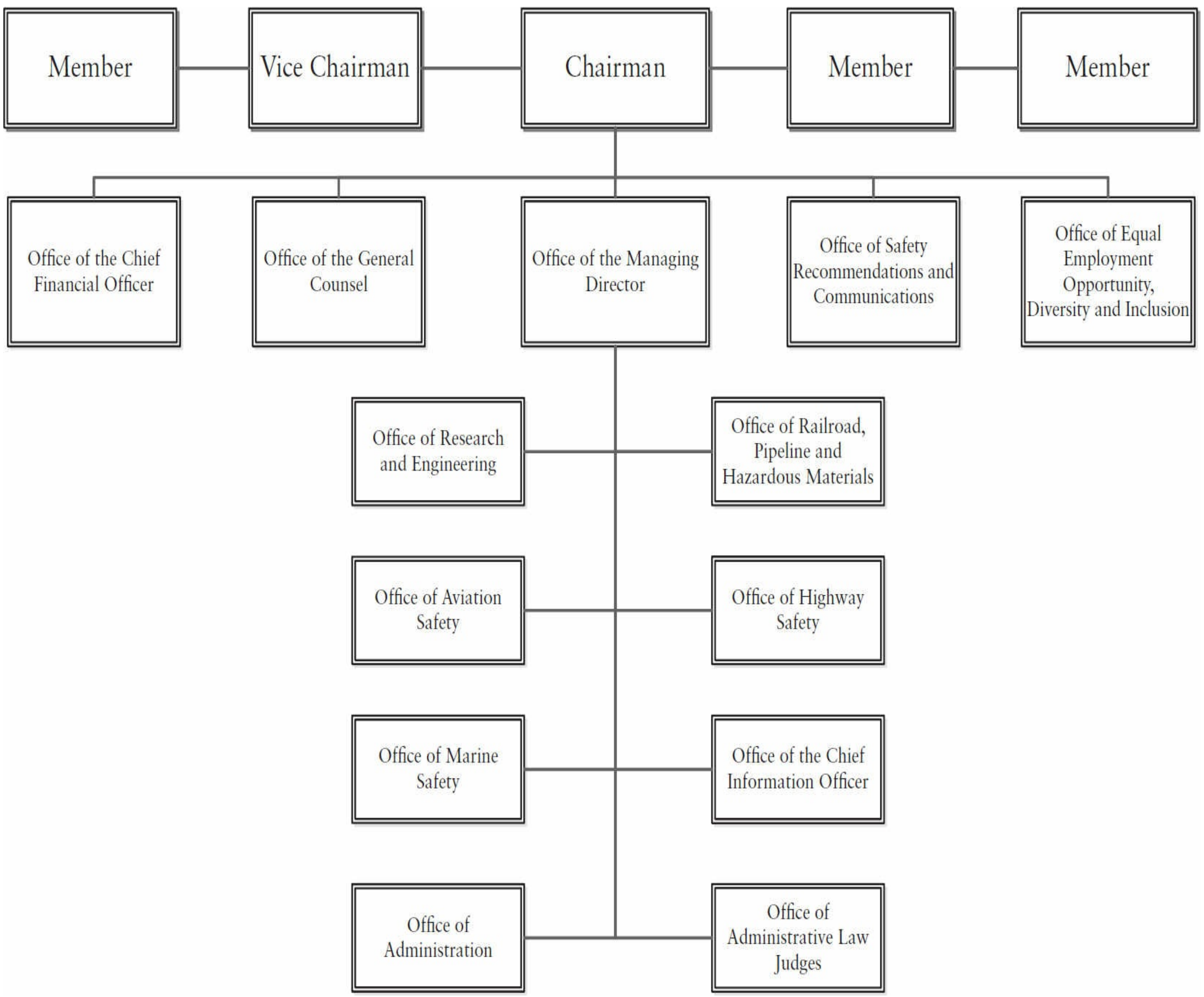

FIGURE 6-4 National Transportation Safety Board organizational chart. (*Source: NTSB*)

The top organizational layer consists of the five board members, each

nominated by the U.S. President and confirmed by the Senate to serve 5-year terms. A Chairman and a Vice Chairman are designated from these five board members. *NTSB board members* establish policy on transportation safety issues and on NTSB goals, objectives, and operations. Board members review and approve major accident reports and safety recommendations, and decide appeals of FAA certificate actions. Individual NTSB board members often serve as spokesman for major accident investigation as part of *Go Teams*, preside over public hearings, make major speeches, and testify before Congressional Committees.

OFFICE OF AVIATION SAFETY

The *Office of Aviation Safety* has the responsibility for investigating aviation accidents and incidents and for proposing probable causes for the Board's approval. With only a modest sized staff the office handles more than 1,700 aviation accidents and incidents annually. The office also works, in conjunction with the other offices, to formulate recommendations to prevent the recurrence of similar accidents and incidents and to improve aviation safety as a whole. Most of the field investigations are led by a regional investigator from one of the four offices:

- Eastern Region
- Central Region
- Western Pacific Region
- Alaska Region

OFFICE OF ADMINISTRATIVE LAW JUDGES

By necessity, much of the NTSB's work deals with the inanimate, such as aircraft structures, railroad tracks, pipelines, operating rules and procedures, and so forth. However, there is one unit of the NTSB, the *Office of Administrative Law Judges*, which most often deals directly with the individual. The role of the Office of the Administrative Law Judge is to act as an initial appeals court for persons who might have had licenses or certificates suspended, revoked, or modified by the FAA or the DOT. The license holders range from pilots and aircraft mechanics to merchant seamen and flight dispatchers. But the authority of the law judge also extends beyond the individual to include the hearing appeals that might involve the loss or suspension of operating certificates issued

for individual aircraft models or to airlines.

The law judges function as trial judges, administering oaths, receiving evidence, ruling on motions, issuing subpoenas, and regulating the course of the hearing. For example, Figure 6-5 shows Chief Administrative Law Judge Alfonso Montano swearing in Christopher A. Hart as the 13th Chairman of the NTSB. Many hearings are held outside the Washington, D.C., area.

FIGURE 6-5 Swearing in the new NTSB chairman. (*Source: NTSB*)

The law judge's initial decisions and orders are appealable to the full NTSB. Either party to the proceeding, the airman or the FAA, may appeal the judge's decision to the NTSB. When a petition for reconsideration is not filed, then the NTSB's order becomes final if not appealed to the U.S. Court of Appeals. Only the airman or seaman can take an appeal to the U.S. Court of Appeals. The FAA and the U.S. Coast Guard, in the case of seamen, do not have the right of appeal to the court as government agencies. On review, the court has the power to

affirm, modify, or set aside the full NTSB's opinion and order, in whole or in part, and if needed, further proceedings by the NTSB.

Accident Investigation Process

When a major commercial aviation accident occurs, an NTSB go-team, led by an *investigator-in-charge* (IIC), is dispatched from the agency's Washington, D.C., headquarters to the accident site, usually within a couple of hours of notification of the event. The IIC, a senior air safety investigator with the NTSB's Office of Aviation Safety (OAS), organizes, conducts, and manages the field phase of the investigation, regardless of whether a board member is also present on the scene. The IIC will oversee all facets of the investigation to include assessing the factual circumstances of the crash (on site and afterward), preparing final reports for submission to the board members, initiating safety recommendations to prevent future accidents, and participating in foreign accident investigations.

The IIC has the responsibility and authority to supervise and coordinate all resources and activities of the field investigators. The NTSB go-team may form as many as 10 investigative groups. Specialist "working group" teams may be formed around subject matter areas, such as power plants, systems, structures, operations, air traffic control, human factors, weather, and survivability. Groups associated with the cockpit voice recorder (CVR) and flight data recorder (FDR), pictured in Figure 6-6, are formed at the NTSB laboratory in Washington. All NTSB staff assigned to a particular investigation are under the direction of the IIC.

FIGURE 6-6 Receiving the CVR and FDR (black boxes) from Asiana Flight 214 for analysis. (*Source: NTSB*)

PARTY PROCESS

Increasingly, the NTSB has no choice but to conduct its investigations in the glare of intense media attention and public scrutiny. As commercial air travel has become routine for millions of passengers, major accidents have come to be viewed by some as nothing short of national catastrophes. At the same time, an NTSB statement of cause may be nothing short of catastrophic for the airline, aircraft manufacturer, or other entity that may be deemed responsible for an accident.

A very real, albeit unintended, consequence of the NTSB's safety investigation is the assignment of fault or blame for the accident by both the courts and the media. Hundreds of millions of dollars in liability payments, as well as the international competitiveness of some of the most influential U.S. corporations, rest on the NTSB's conclusions about the cause of a major accident. This was not the system that was intended by those who supported the creation of an independent investigative authority, but it is the environment in which the investigative work of the agency is performed today.

Given the amazing complexities of accidents and the impossibility of having in-house experts on every component and system of modern aircraft, the NTSB relies on teamwork to resolve accidents, naming "parties" to participate in the

investigation that include manufacturers, operators, and, by law, the FAA. The so-called *party system* enables the NTSB to leverage its limited resources and personnel by bringing into an investigation the technical expertise of the companies, operator employee organizations (such as unions), and individuals who were involved in the accident or who might be able to provide specialized knowledge to assist in determining the probable cause.

Except for the FAA, party status is a privilege, not a right, and party members are occasionally kicked out of investigations for not following the protocols inherent in the party system. The IIC has the discretion to designate the parties that are allowed to participate in an investigation, and each party representative must work under the direction of the IIC or senior NTSB investigators at all times. No members of the news media, lawyers, or insurance personnel are permitted to participate in any phase of the investigation. Claimants or litigants (victims or family members) are also specifically prohibited from serving as party members.

The specialists that any party assigns to an investigation must be employees of the party and must possess expertise to assist the NTSB in its investigation. Providing the safety board with technical assistance gives parties many opportunities to learn what happened and to formulate theories as to the cause of the accident. Party representatives are not permitted to relay information to corporate headquarters without the consent of the IIC, and then only when necessary for accident prevention purposes. Information is not to be used for litigation preparation or for public relations.

The first 2 days following an accident are critical because the evidence is fresh and undisturbed. After people start going through the wreckage, the clues begin to disappear. An airspeed indicator’s needle might be moved, a fuel line might drain, ice on a wing could melt, or leaked hydraulic fluid could sink into the ground. Subtle clues are lost that could reveal possible factors in the accident. Consequently, crash sites are protected from the untrained until the go-team arrives on the scene.

THE GO-TEAM

On 24-hour alert, *go-team* personnel possess a wide range of accident investigation skills. For aviation accidents, a go-team roster could include one of the five members of the NTSB, an air traffic control specialist, a meteorologist, a human-performance expert, an expert trained in witness interrogation, an engine specialist, as well as experts in hydraulics, electrical systems, and maintenance records. Some go-team members are completely intermodal in that their area of

expertise is applicable to each mode, meaning that they may help investigate rail accidents one day and maritime accidents another day. For example, an NTSB wiring expert can apply expertise in that area to any transportation accident involving wiring and may thus be considered intermodal. Human-factors experts fall into this category, as do the NTSB's metallurgists, meteorologists, and hazardous-materials experts. Figure 6-7 shows the moment when team members arrive at the airport nearest an accident to perform the investigation.

FIGURE 6-7 NTSB personnel arriving to take charge of an investigation. (*Source: NTSB*)

Go-team duty is rotated. Immediately after one team has been dispatched, a new list is posted. Like firefighters, go-team members spend many hours doing office work and working on special studies until the inevitable call comes. The FAA usually gets the first word of an accident, followed by the director of the NTSB's regional or field office. This office notifies the go-team, the board member on duty, the NTSB chair, and the public affairs division. The team is normally on its way within 2 hours. Until it arrives, an investigator from the nearest NTSB field office secures the crash site with the help of local authorities. Representatives from the aircraft manufacturer, the airline, the engine manufacturer, and the FAA also arrive. If the accident is major, a Board member

of the NTSB accompanies the team.

ACCIDENT SITE

The length of time a go-team remains on the accident site varies with need, but generally a team completes its work in 10 to 14 days. Accident investigations often require off-site engineering studies or laboratory tests that might extend the fact-finding stage. In cases of crew fatalities, a local coroner usually performs autopsies on the flight crew to determine at the outset whether pilot incapacitation might have been a factor. An autopsy can also reveal who was sitting where in the cockpit and who was flying the aircraft, among many other factors. Figure 6-8 shows the appearance of a relatively contained accident site where an aircraft came to rest after overrunning a runway.

FIGURE 6-8 NTSB personnel at an aircraft accident site. (*Source: NTSB*)

After the preliminary steps are completed, the detailed work begins. The go-team is organized into groups of experts, each of which focuses on specific aspects of the investigation. Each group, headed by a group chairperson,

aspects of the investigation. Each group, headed by a group chairperson, concentrates on a specific portion of the investigation. Coordination is orchestrated to ensure investigative coverage in areas where more than one group may have a responsibility. Using their combined knowledge of flying in general and of this aircraft in particular, the investigators work within groups and across groups to compare what they know with what they find in the wreckage. Cameras are an important tool of the trade. Before the team members touch any of the wreckage, they take pictures from various angles and distances and make notes into voice recorders for subsequent reference during analyses.

Operational factors experts in the disciplines of air traffic control (ATC), operations, and weather support major investigations with intensive work in their specialties. The ATC specialists examine navigation and communication facilities, procedures, and flight handling, including ground-to-air voice transmissions, and develop flight histories from Air Route Traffic Control Center (ARTCC) and terminal facility radar records. Other specialists examine factors involved in the flight operations of the carrier and the airport and in the flight training and experience of the flight crew. Weather specialists examine meteorological and environmental conditions that may have contributed to the accident.

Human-performance specialists examine the background and performance of persons associated with the circumstances surrounding an accident, including the person's knowledge, experience, training, physical abilities, decisions, actions, relationships, equipment design, ergonomics, and the work environment.

Aviation engineering experts from four areas provide strong technical investigative skills. Power-plant specialists examine the airworthiness of aircraft engines, while structures experts examine the integrity of aircraft structures and flight controls as well as the adequacy of design and certification. Systems specialists examine the airworthiness of aircraft flight controls and avionic, electrical, and hydraulic systems. Maintenance specialists also examine the service history and maintenance of aircraft systems, structures, and power plants.

Survival factors experts investigate what affected the survival of persons involved in accidents, including the causes of injuries and fatalities. These investigators also examine cabin safety and emergency procedures, crashworthiness, equipment design, emergency responsiveness, and airport certification.

LABORATORY

While the investigators work on site, the NTSB's materials laboratory in

Washington, D.C., performs detailed analyses on items found at the site. One of the finest of its kind in the world, this NTSB laboratory is designed to support investigators in the field. For example, the laboratory has the capability to “read out” CVRs and decipher FDRs. CVRs allow investigators to listen to sounds recorded on the flight deck, such as power changes, alarms, and verbal communication. FDRs provide investigators with such key factors as airspeed, altitude, vertical acceleration, and elapsed time. These two so-called *black boxes* provide investigators with a profile of an aircraft during the crucial last minutes of flight.

Metallurgy is another of the laboratory’s critical skills. NTSB metallurgists perform post-accident analysis of wreckage parts. The laboratory is capable of determining whether failures resulted from inadequate design strength, excessive loading, or deterioration in static strength through fatigue or corrosion. Figure 6-9 shows an NTSB investigator methodically scrutinizing the condition of a part from the wreckage of an aircraft.

FIGURE 6-9 Carefully examining aircraft wreckage. (*Source: NTSB*)

The investigation of the American Airlines DC-10 that lost its left engine after takeoff from Chicago’s O’Hare Airport in May 1979 probably could not have been concluded without the help of the materials lab. Preliminary

investigations led metallurgists to focus on the aft bulkhead of the left engine pylon, the vertical member of the wing from which the engine is suspended. They found the overstressed area where the engine broke off. As suspected, a trail of fatigue marks was found leading up to the overstressed area. But the real mystery turned up when the metallurgists followed the fatigue marks to their point of origin, only to discover another overstressed area, and nothing else. The first overstress had caused the fatigue, and the fatigue had caused the final break. But what had caused the initial overstress?

The metallurgists and specialists reviewed the aircraft's maintenance records and found that when removing the engines, a maintenance crew had used a forklift to help lower the entire engine-pylon assembly. Although the crew did not realize it at the time, the method was causing hidden damage at the points where the engine and pylon were fastened to the wing. As a result of these findings, the engine removal procedure was changed for future generations.

ACCIDENT REPORT PREPARATION

Following completion of the on-scene phase of the investigation (which may last for several days or weeks), each NTSB group chair (the senior investigator overseeing a specific area of the investigation) completes a factual report on his or her area of responsibility. The reports are likely to include proposed safety recommendations to correct deficiencies and prevent future similar accidents. All factual material is placed in the public docket that is open and available for public review. Thereafter, the investigators involved in the case begin an often lengthy period of further fact gathering, usually involving one or more public hearings, and final analysis of the factual information collected.

There is no time limit on NTSB investigative activity. Safety board procedures have a target date for completion of the *final accident report* within 1 year of the date of the accident, but commercial aviation investigations have taken as little as 4 months for relatively simple but serious incidents and as much as 4 years for complex accidents.

A key milestone in the report process is the group chairs' preparation of analytical reports in their respective areas of expertise. The parties may contribute to the analytical reports through their continued contact with the NTSB group chairs and the IIC, but parties are not allowed to review, edit, or comment on the analytical reports themselves. The parties also contribute to the safety board's analytical process through written submissions, which are sometimes extensive and become part of the public docket.

PUBLIC HEARING

Following an accident, the NTSB may decide to hold a public hearing to collect added information and to discuss at a public forum the issues involved in an accident. Every effort is made to hold the hearing promptly.

A hearing involves NTSB investigators, other parties to the investigation, and expert witnesses called to testify. At each hearing, a Board of Inquiry is established that is made up of senior safety board staff, chaired by the presiding NTSB member. The *Board of Inquiry* is assisted by a technical panel. Some of the NTSB investigators who have participated in the investigation serve on the technical panel. Depending on the topics to be addressed at the hearing, the panel often includes specialists in the areas of aircraft performance, power plants, systems, structures, operations, air traffic control, weather, survival factors, and human factors. Those involved in reading out the cockpit voice recorder and flight data recorder, and in reviewing witness and maintenance records, also might participate in the hearing.

Expert witnesses are called to testify under oath about selected topics to assist the safety board in its investigation. The testimony is intended to expand the public record and to demonstrate to the public that a complete, open, and objective investigation is being conducted. The witnesses who are called to testify are selected because of their ability to provide the best available information on the issues related to the accident.

Following the hearing, investigators will gather additional needed information and conduct further tests identified as necessary during the hearing. After the investigation is complete and all parties have had an opportunity to review the factual record, a technical review meeting of all parties is convened. That meeting is held to ensure no errors exist in the investigation and to determine if everything necessary has been accomplished.

FINAL ACCIDENT REPORT PREPARATION

With the completion of the fact-finding phase, the accident investigation process enters its final stage—analysis of the factual findings. The analysis is conducted at the NTSB's Washington, D.C., headquarters. The final accident report includes a list of factual findings concerning the accident, analysis of those findings, recommendations to prevent a repetition of the accident, and a probable-cause statement.

The IIC and the NTSB senior staff create a final draft report, called the notation draft, for presentation to the board members. This draft includes safety

recommendations and a finding of probable causes. Following a period for review of the draft report, a public meeting of the board members is held in Washington, D.C. The NTSB staff will present and comment on the draft report; party representatives are permitted to attend but may not make any kind of presentation or comment. At this meeting, the board members may vote to adopt this draft, in its entirety, as the final accident report; may require further investigation or revisions; or may adopt the final accident report with changes that are discussed during the meeting.

Safety recommendations resulting from major investigations generally are included in the final accident report; however, in the interest of safety, they may be issued at any time during the course of an investigation if the NTSB deems it necessary.

SAFETY RECOMMENDATIONS

The safety recommendations made to the FAA are the NTSB's end product. Nothing takes a higher priority, and nothing is more carefully evaluated. In effect, the recommendation is vital to the NTSB's basic role of accident prevention because it is the lever used to bring changes and improvements in safety to the nation's transportation system. According to the FAA, the NTSB and the FAA agree on a course of action about 88% of the time. With human lives involved, timeliness also is an essential part of the recommendation process. As a result, the NTSB issues a safety recommendation as soon as a problem is identified without necessarily waiting until an investigation is completed and the probable cause of an accident determined. In its mandate to the NTSB, Congress clearly emphasized the importance of safety recommendations, saying the NTSB shall "advocate meaningful responses to reduce the likelihood of recurrence of transportation accidents." Each recommendation issued by the NTSB designates the person, or the party, expected to take action, describes the action that the NTSB expects, and clearly states the safety need to be satisfied.

Recommendations are based on findings of the investigation and may address deficiencies that do not pertain directly to what is ultimately determined to be the cause of the accident. For example, in the course of its investigation of the crash landing of a DC-10 in Sioux City, Iowa, in 1989, the NTSB issued recommendations on four separate occasions before issuing its final report. In the TWA Flight 800 investigation in 1996, once it was determined that an explosion in the center fuel tank caused the breakup of the aircraft, the NTSB issued urgent safety recommendations aimed at eliminating explosive fuel/air

vapors in airliner fuel tanks.

Occasionally, a single crash investigation can have major ramifications on the entire commercial aviation industry. Such was the case of Colgan Air Flight 3407, a commuter airline accident which occurred on February 12, 2009 near Buffalo, New York. Figure 6-10 shows the appearance of the wreckage from Flight 3407. From an NTSB point of view, this accident investigation was extraordinary in its sweeping scope, number of recommendations, and speed of delivery to the public. The issues presented and explored during the public hearing and investigation were the following:

FIGURE 6-10 The wreckage of Colgan Flight 3407. (*Source: NTSB*)

- Effect of icing on aircraft performance
- Cold weather operations
- The "sterile cockpit" (inappropriate discussions between the pilots)
- Flight crew experience and training
- Human fatigue management
- Stall recovery

The final NTSB report was issued with unprecedented speed, less than 1 year

after the accident, and the Board made 28 safety recommendations which covered a wide range of safety issues that were factors in this accident, especially pilot training and fatigue. This single accident has had a profound effect on commercial aviation safety today.

INVESTIGATING A GENERAL-AVIATION ACCIDENT

The investigation of general-aviation accidents, often involving light recreational aircraft, is a simpler process requiring fewer staff members per accident. Inasmuch as the NTSB investigates many general aviation accidents per year, abbreviated investigations are generally necessary, given the agency's limited staff and budgetary resources. Most general-aviation accident investigations are conducted by one of the NTSB's regional or field offices. In a *field investigation*, at least one investigator goes to the crash site; a limited investigation is carried out by correspondence or telephone. Some, but by no means all, general aviation accidents generate safety recommendations approved by the NTSB members.

FAMILY ASSISTANCE AND THE TRANSPORTATION DISASTER ASSISTANCE DIVISION

Following the enactment of the *Aviation Disaster Family Assistance Act of 1996*, the President designated the NTSB as the lead federal agency for the coordination of federal government assets at the scene of a major aviation accident and as the liaison between the airline and the families. The role of the NTSB includes integrating the resources of the federal government and other organizations to support the efforts of state and local governments and the airlines to aid aviation disaster victims and their families. The NTSB's *Transportation Disaster Assistance Division* assists in making federal resources available to local authorities and the airlines, for example, to aid in rescue and salvage operations and to coordinate the provision of family counseling, victim identification, and forensic services. The safety board has sought to maintain a distinct separation between family assistance activities and the NTSB's technical investigative staff.

FAA RESPONSIBILITIES DURING AN INVESTIGATION

Accident investigation is also the responsibility of each FAA Flight Standards District Office (FSDO), which maintains a pre-accident plan that is tailored to that office's specific requirements, such as the geographic location, climate

that office's specific requirements, such as the geographic location, climate, staffing, and resources. For example, the logistical requirements to investigate an accident in Alaska may require snowmobiles and cold weather clothing, whereas a pre-accident plan for investigations in Florida may require airboats and scuba diving expertise. The FAA works very closely with the NTSB, ensuring that:

- All facts and circumstances leading to the accident are recorded and evaluated.
- Actions are taken to prevent similar accidents in the future.

Determining whether:

- Performance of FAA facilities or functions was a factor.
- Performance of non-FAA owned and operated air traffic control (ATC) facilities or a navigational aid was a factor.
- Airworthiness of FAA-certified aircraft was a factor.
- Competency of FAA-certified airmen, air agencies, commercial operators, or air carriers was involved.
- Federal Aviation Regulations were adequate.
- Airport certification safety standards or operations were involved.
- Airport security standards or operations were involved.
- Airman medical qualifications were involved.
- There was a violation of Federal Aviation Regulations.

The FAA conducts investigations and submits factual reports of the investigations to the NTSB on accidents delegated to the FAA by the NTSB. The FAA's principal investigator at an accident is also called the investigator-in-charge (IIC). This individual directs and controls all FAA participation in the accident until the investigation is complete. Included is the authority to procure and use the services of all needed FAA personnel, facilities, equipment, and records. The FAA IIC (not to be confused with the NTSB IIC) is under the control and direction of the NTSB IIC in an NTSB-conducted investigation. When accident investigations are delegated to the FAA by the NTSB, the FAA IIC becomes an authorized representative of the NTSB. All the investigative authority prescribed in the applicable NTSB regulations falls to this person. All other FAA personnel involved in such an investigation report to the IIC and are responsible to that person for all reports they have prepared or received during the investigation.

NTSB ACCIDENT DATABASES AND SYNOPSES

The NTSB aviation accident database contains information dating from 1962 about civil aviation accidents and selected incidents within the United States, its territories and possessions, and in international waters. Generally, a preliminary report is available online within a few days of an accident. Factual information is added when available, and when the investigation is completed, the preliminary report is replaced with a final description of the accident and its probable cause. Full narrative descriptions may not be available for dates before 1993, cases under revision, or where NTSB did not have primary investigative responsibility.

NTSB MOST WANTED AVIATION SAFETY IMPROVEMENTS

Since the NTSB lacks regulatory authority over the FAA and aviation industry, one of its most important functions is to strongly recommend and advocate appropriate FAA actions that will improve aviation safety. The Board satisfies this mandate by publishing and frequently updating its "Most Wanted List" of safety improvements for all modes of transportation covered by the NTSB, although the aviation improvements are the ones of interest to readers of this book. The most current *NTSB Most Wanted List* can be found on the NTSB Web site. Following are the elements contained in the latest NTSB Most Wanted List that impact commercial aviation, as provided by the NTSB Web site. The reader is encouraged to check the most current NTSB Web site for updates and emerging information on the latest safety issues.

NTSB MOST WANTED LIST FOR 2017–2018

REDUCE FATIGUE-RELATED ACCIDENTS. Human fatigue affects the safety of the traveling public, regardless of the mode of transportation. When people are not awake and alert, they cannot perform at their best, thus endangering themselves and others. To make matters worse, fatigue actually impairs our ability to judge just how fatigued we really are. Preventing fatigue requires a comprehensive approach that combines the following items: research, education and training, technologies, treatment of sleep disorders, hours-of-service regulations, and on- and off-duty scheduling policies and practices.

STRENGTHEN OCCUPANT PROTECTION. Sadly, there have been many accidents

where improved occupant protection systems could have reduced injuries and even saved lives. For example, in the 2013 San Francisco Asiana Flight 214, two of the three fatalities were the result of passengers not wearing their seatbelts. Additionally, the Federal Aviation Administration exempts children under age 2 from wearing a seatbelt, allowing them to travel unrestrained on an adult's lap. Necessary improvements include the increased use of existing restraint systems and better design and implementation of occupant protection systems that preserves survivable space and ensures ease of evacuation.

EXPAND USE OF RECORDERS TO ENHANCE TRANSPORTATION SAFETY. Investigators need to have an accurate insight into how accident sequences unfolded in order to prevent future, similar events. Cockpit voice and data recorders have been a critical tool in helping to achieve this goal. However, some questions could only have been answered through the data provided from an image (video) recorder. Image recordings can help to fill gaps by providing investigators and operators first-hand knowledge of crew activities. To address these problems, regulations should require the use of cockpit voice and image recorders, but until that time, operators should proactively procure this technology to improve their operational and safety oversight.

REQUIRE MEDICAL FITNESS. When pilots have untreated or undiagnosed medical conditions that prevent them from doing their job safety, people can be seriously injured or die. Requiring medical fitness for duty can prevent accidents that can lead to other tragic outcomes. For example, the NTSB has found that obstructive sleep apnea has been a factor in multiple accidents, as aviation lacks a complete screening process for this condition. The NTSB has made recommendations for a comprehensive medical certification system that will ensure fitness for duty before the operation of a plane.

ELIMINATE DISTRACTIONS. For over 10 years, the NTSB has recognized that personal electronic devices are a cause or contributing factor to accidents. People have a limited attention span, so each auxiliary task impairs our processing of the primary task. Focusing on any other task than what is ahead can impair performance and lead to deadly consequences. Although commercial airlines recognize the need for a "sterile cockpit," meaning pilots should refrain from nonessential activities and conversation during critical phases of flight, other aviation professionals could make good use of the philosophy during their work in support of flight operations.

End Alcohol and Other Drug Impairment in Transportation. Impaired judgment can be the result of both prescribed and over-the-counter medicines. Complex machinery like aircraft require operators, aviation maintenance technicians, air traffic controllers, and support personnel to perform at their best. According to a 2014 Safety Study by the NTSB that focused on drug use trends in aviation, the presence of potentially impairing drugs in pilots increased from 11% during 1990–1997 to 23% during 2008–2012. In the same time periods, positive marijuana results increased from 1.6% to 3.0%. However, the most commonly found impairing substance in fatal crashes was diphenhydramine, a sedating antihistamine found in over-the-counter medications. More and better data will help us understand the scope of the problem and the effectiveness of countermeasures. This will help spread good information for operators to make an informed decision about the effects of different drugs or taking medication. Additionally, pilots should consult with their doctor before taking a medication and discuss the impairing effect of any medical condition as it might increase their risk of having an accident.

Ensure the Safe Shipment of Hazardous Materials. Although this topic has been a perennial hazard in aviation, public awareness of the problem skyrocketed in 1996 following the 110 fatalities from the crash of ValuJet Flight 592, which was a McDonnell Douglas DC-9, into the Everglades 11 minutes after departing from Miami. Investigation revealed a series of factors, with one of them being improperly secured cargo of over 100 expired chemical oxygen generators that resulted in a fire in the cargo compartment. Fast forward 20 years, and the new featured hazard is the lightweight, high-energy density lithium batteries, including lithium-ion batteries, which are commonly used to power portable electronic devices (PEDs). The reader must realize that most passengers onboard a commercial aircraft today probably have such a battery in their possession. Some power arrangements in PEDs are more risky than others. In October 2016, the FAA banned traveling by air with the Samsung Galaxy Note 7 due to the risk the phone poses for onboard fires. PEDs are only one type of onboard hazard among a range of potential hazards that may include power tools, other household products in the passenger cabin, and inappropriately labeled and screened shipments in cargo compartments.

CASE STUDY: SPANAIR FLIGHT 5022 ACCIDENT

Throughout this chapter, we have discussed how investigations require a large number of specialists to collaborate and what their responsibilities look like

when a crash happens. There are many people involved, all simultaneously working on different pieces of the puzzle. To illustrate how this process works in the real world, we will examine the 2008 crash of a McDonnell Douglas MD-82 operating as Spanair Flight 5022 that killed 154 people.

The accident aircraft was being operated on a scheduled Spanish flight from Madrid to Gran Canaria Airport when it crashed on August 20, 2008. Prior to takeoff, the pilots had failed to deploy the required flaps and slats of the plane. These devices help a plane create lift, which allows the plane to fly at the slow speeds associated with takeoff and landing. Without them deployed, the plane could not generate enough lift to keep the aircraft airborne, and thus it impacted the terrain immediately after takeoff.

The flight was a Star Alliance codeshare, meaning that it carried passengers booked by multiple airlines, and was operating on behalf of Lufthansa. Figure 6-11 shows the recovery effort for a fuselage section from the wreckage in Madrid.

FIGURE 6-11 A fuselage section of Spanair Flight 5022. (*Source: Comisión de Investigación de Accidentes e Incidentes de Aviación Civil, CIAIAC*)

Background

Spanair was a Spanish airline that began operations in March 1988. Originally, it was a joint venture between Scandinavian Airlines and Viajes Marsans set up to conduct European charters. In 1991, it grew to include long-haul flights to the United States, Mexico, and the Dominican Republic, and in 1994, launched domestic service within Spain.

Spanair's fleet consisted mostly of planes in the McDonnell Douglas MD-80/90 series. The accident aircraft belonged to this category, as it was an MD-82. The model is a variant of the MD-80, which is a twin-engine, short-to-medium haul commercial jet airliner. The MD-82 has a takeoff warning system with an audible warning for the pilots, which warns if the aircraft has improper takeoff configuration when the takeoff is initiated. This feature is important to keep in mind as we explore the Spanair 5022 accident. The system is supposed to act as a cross-check for pilots who may have forgotten to complete some of the steps on the pre-departure checklist. However, the failure of the takeoff warning system itself to alert of a discrepancy is not uncommon in the MD-80 series and has been associated with other fatal accidents, including Northwest Flight 255 at Detroit in 1987.

In any accident, investigators complete rigorous profile sketches of the people involved to understand what was going on in their life and to see if it could have affected their ability to do their job. The backgrounds of the pilots flying Spanair Flight 5022 were therefore examined. Prior to and during the flight, the crew seemed to be fit for duty. The Captain's credentials were in good standing and he had previously severed as a captain and test pilot in the Spanish Air Force. He had been with the airline for 9 years. His file reflected that he was an above average pilot although he could improve his crew resource management skills. He had been described as disciplined, precise, and meticulous in his job, and someone who would adhere to procedures rigorously. He had reportedly been in good spirits prior to the flight.

The other pilot, who was the First Officer, was 31 and hired in February 2007. At the time of the accident, Spanair was experiencing employee layoffs which would have affected the First Officer. He had planned to find another job and keep flying. However, colleagues had described him a serious and disciplined pilot who made an effort to collaborate. He seemed to love flying and be happy to do so.

It is also important for investigators to create a timeline of the flight because it helps understand how the pilots interacted with the plane and the plane's responses to pilot input. Looking at the sequence of events for Spanair 5022 helps paint a picture of what was going on in the cockpit and with the plane.

> **13:24:57** After the pilots had been cleared for takeoff, they cancelled the departure when they noticed that there was an abnormal reading in one of the external probes of the aircraft that was used to generate data for cockpit instruments.

13:42:50 Two maintenance personnel reported to the aircraft to check on the issue. Maintenance did detect something wrong.

13:54:02 The minimum equipment list commonly referenced by pilots and maintenance personnel stated that the airplane could be dispatched for flight with the probe heating inoperative as icing conditions were not forecasted for the flight. The Maintenance Technician proposed that the pilots pull breaker Z-29 to disconnect the electrical supply to the probe heater. The plane was then released for departure.

14:08:43 The Crew accomplished the “Prestart” and “Before Start” checklists. The Captain anticipated some of the items on the “Before Start” checklist before they were read by the First Officer.

14:12:08 Once the engines were started, the “After Start” checklist was performed. However, the item on the checklist to check the flaps/slats was skipped, and the Captain asked the First Officer to request permission from ATC to start taxing to the runway for takeoff.

14:15:56 The Crew accomplished the “Taxi” checklist.

14:22:06 The First Officer accomplished the “Takeoff Imminent” checklist.

14:23:14 Spanair Flight 5022 confirmed clearance for takeoff.

13:54:02 The Crew commented that the auto-throttle was not working and they would have to do a manual takeoff.

14:24:10 Throughout the takeoff and until the end of the cockpit voice recorder, no sounds were recorded emanating from the takeoff warning systems.

14:24:14 The plane alerted the Crew that there was an aerodynamic stall. The First Officer thought this may be engine failure, and the Captain asked how to turn off the warning. At this time, the pitch angle was 15.5° and the bank angle 4.4°. The bank angle increased to a maximum of 20°. From that moment on, there was a warning coming from the Enhanced Ground Proximity Warning System for the bank angle as well as the alternating horn and voice stall warning.

14:24:24 Sounds corresponding to the initial impact with the ground.

14:24:36 The flight data recorder finished recording.

INVESTIGATION

Investigators are trained to avoid distractions from so-called *red herrings*, which is an expression referring to information that appears significant but actually is not and which draws attention away from the issue at hand. Similarly, investigators are taught to control the human tendency to speculate, particularly in the absence of concrete evidence, and which is common in the media following an accident. Early speculations about the Spanair accident suggested that the plane crashed because of loss of engine power. People thought this because surviving passengers had said they saw flames and then heard an explosion *before* the Spanair jet crashed. However, footage from the security camera did not show an explosion or a fire during the departure. The video showed the plane performing a long takeoff roll and falling after a few hundred feet.

Later on in the investigation, authorities also released information that a central computer system used to monitor technical problems in the aircraft was infected with malware. The malware could have infected the computer in a number of ways, such as through a USB sticks or the network. Therefore it was surmised that the computer may have failed to detect three technical problems with aircraft, all of which should have been addressed before the Crew attempted to perform the takeoff.

To establish the findings, causes, and recommendations associated with the accident, a team of investigators, or the “party members” as we referred to earlier in this chapter, formed to gather and analyze clues. The investigation party included members from the following organizations:

- Spanish Civil Aviation Accident and Incident Investigation Commission
- United States NTSB
- European Aviation Safety Agency
- ICAO
- FAA
- Boeing
- Pratt and Whitney
- Spanair

With such a team of highly skilled professionals, investigators were able to conduct several engineering and technical analyses with data collected from the wreckage. Tests centered on the flaps and slats. Parts from these components

were sent to the National Institute for Aerospace Technology for analysis. The light bulbs were also looked at to determine the operating conditions that existed during the sequence of the impacts of the aircraft with the terrain. Such analyses can reveal if a bulb was illuminated at the time of impact and can thus help investigators determine if certain systems were on or off at the time of the accident.

Much of the technical investigation focused on why the takeoff warning system (TOWS) did not function as expected, which if it had, would quite possibly have prevented the accident by warning that the aircraft was not properly configured for takeoff. If such a warning had been issued, it would have been reasonable to expect the Pilots to have aborted the takeoff while still at relatively slow speed, thus completely preventing the accident. The technical analysis of the TOWS required a teardown of the R2-5 Relay, as shown in Figure 6-12. Unfortunately, the findings of the analysis were not conclusive, which means that the investigators knew that the TOWS had failed to properly function, but were not able to fully determine the reasons behind the failure.

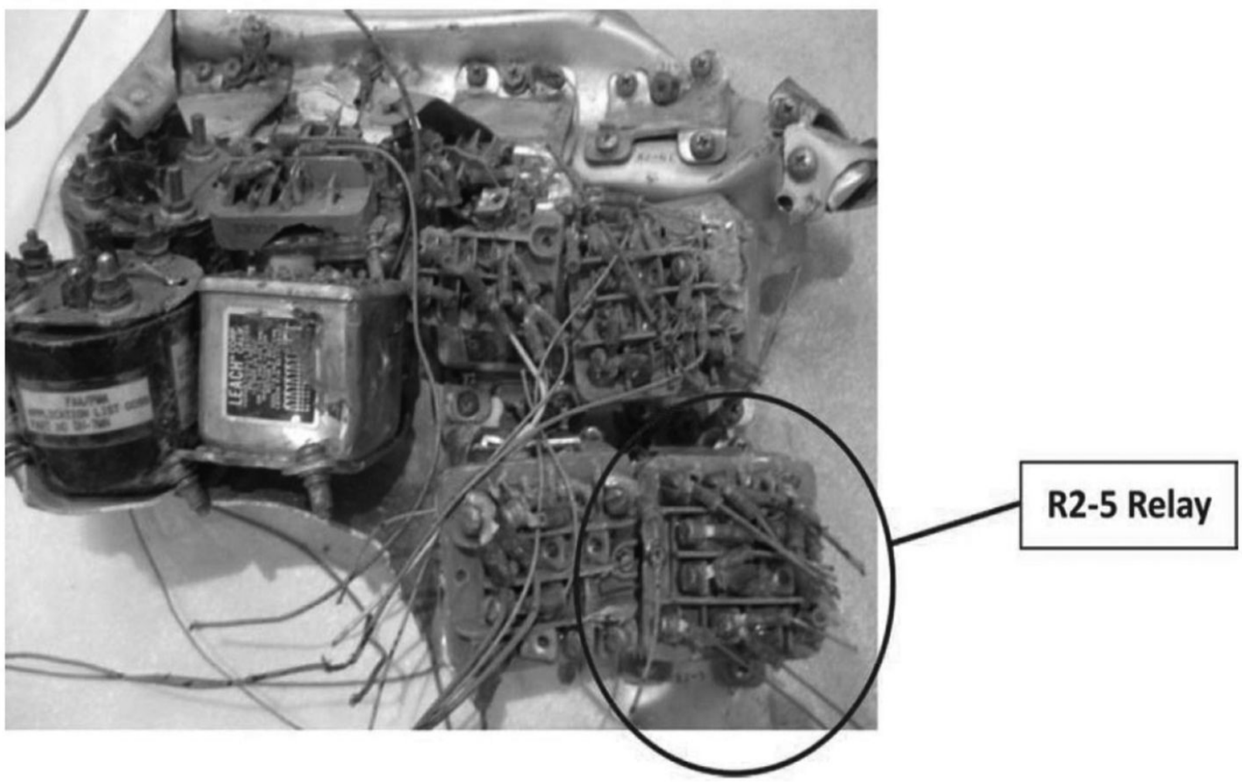

FIGURE 6-12 Relays used for analysis in Spanair Flight 5022. (*Source: Comisión de Investigación de Accidentes e Incidentes de Aviación Civil, CIAIAC*)

A human factors investigation was performed in addition to the technical and

engineering analyses. With the Spanair Flight 5022 accident, investigators looked at training procedures, company policies, structure and organization, and operational procedures. An interesting finding was that the company's policy was to compensate passengers if the airplane doors were closed more than 15 minutes after the scheduled departure time for reasons that were attributed to the company. Could it be that the pilots felt pressed to leave on time as a result of this policy? Results of audits were also scrutinized. Boeing had noted that takeoff and approach briefings sounded memorized and too long.

Findings

After the investigators collected and analyzed all the information, it was time to write the accident report. One key section of the report is the Findings, which for Spanair Flight 5022 resulted in a long list of 78 total findings. Several major findings are listed below:

- The Crew did not observe the sterile cockpit principle. In addition to using cellular telephones while taxiing, they held conversations in the cockpit with a third person on topics that were irrelevant to their flight activities. This contributed to distracting the crew from its flight duties.
- The Pilots used the Spanair checklists but did not fully complete them. Some items in the checklists were omitted, and the actions required in other items were not carried out. Deviations occurred during the execution of operation procedures and the lack of oversight resulted in the flaps and slats not being selected to the proper position and then subsequently not verified as being in the correct position.
- When the "After Start" checklist was interrupted, the Crew missed its first opportunity to verify that the airplane was properly configured for takeoff.
- By omitting the "Takeoff Briefing" item in the "Taxi" checklist and doing a visual inspection during the "Takeoff imminent" checklist that did not constitute an actual confirmation of the position of the flaps and slats, the Crew missed additional opportunities to notice and correct their error in configuring the airplane.
- The TOWS did not issue any warnings during the takeoff run regarding the improper configurations of the airplane.

Causes

Once the findings have been established, investigators determine the causes.

Doing this allows safety professionals to build up to the most important part of the report, which will be the recommendations. In the accident report of Spanair Flight 5022, the Commission determined that the Crew had lost control of the plane as a result of stall. The stall was initiated by the improper configuration of flaps and slats that stemmed from mistakes made by the Pilots. The Crew did not detect that the plane was in the wrong configuration because they did not properly use the checklists, which would have prompted them to verify the position of the flap/slats when preparing for the flight. Items they neglected to do during the process include the following:

- Selecting the flap/slats with the associated control lever in the “After Start” checklist
- Cross-checking the flap and slat indicating lights when executing the “After Start” checklist
- Checking the flaps and slats during the “Takeoff briefing” during the “Taxi” checklist
- A last check of configuration during the “final” items on the “Takeoff Imminent” checklist.

There were also a few items that were contributing factors to the crash. First, the takeoff warning system did not alert the Pilots that the takeoff configuration was incorrect. However, the reason for this failure could not be established by the investigation team. Second, improper crew resource management caused a deviation from normal operating procedures during unscheduled interruptions to flight preparations.

RECOMMENDATIONS

The accident report is all about the recommendations. Establishing the findings and causes paves the way for crafting them. Looking at the recommendations for Spanair Flight 5022 will help tie together all the pieces of the investigation and report together. The team released several preliminary safety recommendations and another with the publication of the report. A few of the initial recommendations are listed below, accompanied by the status of the recommendation. Seeing the responses demonstrate how it can be difficult to make change within the industry.

- *REC 01/09*. It is recommended that the FAA and EASA require the

manufacturer, the Boeing Company, to include in its Aircraft Maintenance Manual (AMM) for the DC-9 and MD-80 series, in the Troubleshooting Manual (TSM) for the MD-90 series, and in the Fault Isolation Manual (FIM) for the Boeing 717 series, specifically identified instructions to detect the cause and to troubleshoot the fault involving the heating of the ram air temperature probe while on the ground.

  - *FAA Response*. "… the Maintenance Manual used in conjunction with the wiring diagrams is sufficient for solving malfunctions in the ram air temperature probe system." The FAA also emphasized that it was necessary to adhere to standard operating procedures to avoid risks associated with improper takeoff configuration in aircraft in this mode. The Commission did not find this response satisfactory.
  - EASA Response: None.

- *REC 11/09*. It is recommended that EASA revise the accompanying guidelines and the clarifying material for the CS-25 certification regulations for large transport airplanes so as to consider the human errors associated with faults in takeoff configurations when analytically justifying the safety of the takeoff warning system, and to analyze whether the assumptions used when evaluating these systems during their certification are consistent with existing operational experience and with the lessons learned from accidents and incidents.
  - *EASA Response*. There is a requirement that already mandates an analysis be done so that potential errors a flight crew might reasonably be expected to make are taken into consideration when designing systems. EASA added that all in-service history shows all of these stipulations to be adequate. A review of reported events revealed that all of them involved airplanes as old as or older than the MD-82. Therefore, CS-25 does need to be modified. However, the Commission has not fully provided ways to execute this recommendation.

Some of the new safety recommendations issued with the report included the following:

- It is recommended that the FAA and EASA require takeoff stall recovery as part of initial and recurring training programs of airline transport pilots.
- It is recommended that EASA, in keeping with ICAO initiatives, introduce in its regulations the concept of critical phases of flight and define those activities considered acceptable during said phases.
- It is recommended that EASA develop guidance material for the preparation,

evaluation, and modification of checklists associated with normal, abnormal, and emergency procedures that are based on the criteria that govern safety management systems.

- It is recommended that EASA clarify whether or not checklists are subject to the acceptance of national authorities and, if so, that it draft instructions so that said authorities apply uniform criteria and methodologies, such as methods for assessing the systems and procedures in use at the operators for managing checklists and quality assurance systems in general.
- It is recommended that EASA standardize the crew resource management training that must be provided to the operations inspectors of national authorities, and define the criteria that must be met by said inspectors in order to exercise their duties as inspectors in the area of crew resource management.
- It is recommended that Spanair revise its quality assurance system so that the implementation of any corrective measures adopted by its maintenance organization is effectively monitored.

CONCLUSION

It is human nature to speculate, particularly when powerful emotional events are shrouded in mystery. Aircraft accidents prompt strong emotional responses and confusion. We want fast answers to complex problems; unfortunately though, understanding the reasons behind an aircraft accident requires patience. The mark of a seasoned accident investigator is having the discipline to resist speculating without facts as evidence.

Investigators must assemble to carefully collect and analyze data from the accident site and research background issues that were present, all under the careful leadership of an IIC. The results from these efforts allow the team to establish findings, causes, and recommendations. Some factors associated with an accident will be considered findings, and some of those findings will be determined to have actually caused the accident. Recommendations crafted to address the causes attempt to prevent events similar not only to the accident that was investigated but also to other accidents as well. Actually creating remedial action based on recommendations can be challenging, given that resources are always limited, and recommended actions often require work, expense, or likely a combination of both.

ICAO, the NTSB, and the FAA are governmental organizations that all play pivotal roles in accident investigation. Given the complexity of accidents and the numerous highly technical aspects that need to be assessed, experts from outside

of investigating agencies are heavily relied upon for insights into how components and systems must function and how they may have contributed to an accident. The NTSB refers to the use of such experts as the party system. The technical or engineering analyses and the human factors analyses are the two major components of accident investigations.

The Spanair Flight 5022 tragedy provides a poignant example of the challenges of modern accident investigations in commercial aviation. The difficulties of controlling human error, the complexities of investigative techniques, and the pressure placed by external stakeholder groups, such as law firms and family members, all must be managed adroitly by the team charged with finding out what happened, why it happened, and how to prevent it from happening again.

KEY TERMS

Accredited Representative
Aircraft Accident and Incident Investigation (ICAO Annex 13)
Aviation Disaster Family Assistance Act of 1996
Black Boxes
Board of Inquiry
Cause
Field Investigation
Final Accident Report
Findings
Go-team
Independent Safety Board Act of 1974
International Society of Air Safety Investigators
Investigator-in-Charge
Multicausality
National Transportation Safety Board (NTSB)
NTSB Board Members
NTSB Most Wanted List
Office of Administrative Law Judges
Office of Aviation Safety
Party System
Probable Cause
Recommendations

Recommendations
Safety Risk Management
Three-Step Causation Test
Transportation Disaster Assistance Division

REVIEW QUESTIONS

1. How would you explain the importance of aircraft accident investigation to someone with no aviation background?
2. Detail how the findings, causes, and recommendations of an accident report complement each other. Can you paint the same story of an accident if you were to exclude one of these elements from the accident report?
3. Discuss the role of ICAO and NTSB in international aviation accident investigations. What is an accredited representative?
4. What are the primary responsibilities of the National Transportation Safety Board (NTSB)? Describe the types of accidents investigated by the NTSB. Describe the organizational structure of the NTSB.
5. Do you think there are any disadvantages to the NTSB operating as a separate entity from the FAA?
6. Explain the role of the NTSB investigator-in-charge (IIC) and the NTSB go-team. What is the so-called party system that enables the NTSB to leverage its limited resources? Identify the steps taken in a major accident investigation. What types of activities are performed at the NTSB's laboratory in Washington, D.C.? When are safety recommendations made?
7. What is the purpose of a public hearing? Are hearings ever reopened? What information is included in the final accident report? Distinguish between a field investigation and a limited investigation of a general-aviation accident.
8. Describe the responsibilities of the FAA during a major accident investigation.
9. Describe some of the functions of the NTSB besides accident investigation.
10. What is the purpose of the NTSB Most Wanted List?
11. Which item from the NTSB Most Wanted List do you think poses the biggest threat to aviation safety and why?
12. In the Spanair Flight 5022, where do you think there were breakdowns in crew resource management? Why do you think this accident happened?

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FAA Office of Accident Investigation and Prevention: https://www.faa.gov/about/office_org/headquarters_offices/avs/offices/avp/

ICAO Web site: http://www.icao.int

NTSB 2010-2015 Strategic Plan: https://www.ntsb.gov/about/Documents/Strategic-Plan_2010-2015.pdf

NTSB 2016 Most Wanted List: http://www.ntsb.gov/safety/mwl/Pages/default.aspx

NTSB Accident
Reports: http://www.ntsb.gov/investigations/AccidentReports/Pages/AccidentReports.a

NTSB July 2016 Advisory to Operators of Civil Unmanned Aircraft Systems in the United States: https://www.ntsb.gov/investigations/process/Documents/NTSB-Advisory-

Drones.pdf
NTSB main Web site: http://www.ntsb.gov
NTSB Office of Aviation Safety:
http://www.ntsb.gov/about/organization/AS/Pages/office_as.aspx
NTSB Study on Drug Use Trends in Aviation:
http://www.ntsb.gov/safety/safety-studies/Documents/SS1401.pdf
Spanair Flight 5022 final report in English:
http://www.fomento.gob.es/NR/rdonlyres/EC47A855-B098-409E-B4C8-9A6DD0D0969F/107087/2008_032_A_ENG.pdf

CHAPTER SEVEN

PROACTIVE AVIATION SAFETY

LEARNING OBJECTIVES

After completing this chapter, you should be able to

- Describe the data collection and analyses of FOQA/FDM/FDA programs.
- Explain ASAP reports and the importance of ERC analyses.
- Discuss how ASRS is used to promote commercial aviation safety.
- Understand LOSA data collection and how airlines use the analyses to promote safety.
- Describe AQP and how it relates to airline training.
- Discuss ASIAS and the importance of data de-identification.
- Detail the basic reporting systems used by OSHA and EPA.

INTRODUCTION

Many readers will have heard about the “big data” revolution that continues to spread across all segments of life. Increasingly, managers both within and outside of aviation safety circles are demanding more specialized information to make informed decisions. In the past, aviation relied heavily on data and recommendations from the painful and lengthy process of accident investigations to make safety improvements. That approach has worked very well. However, commercial aviation in many parts of the world now faces what can be called a wonderful dilemma. We are no longer having a sufficient number of serious accidents to provide continuous and significant improvements to safety. There are many hazards and risks to aviation operations, yet the paucity of accidents requires a new, proactive approach.

In past decades, our frequent accident investigations helped us make continuous and significant improvements in areas such as engine reliability, structural inspection processes, weather reporting, and personnel training, and produced numerous technologies that have made airline flying the safest form of transportation today. So where do we go from here? It may appear confusing to the reader at first, but it is a mathematical fact that the same current low accident rate over time will produce more and more accidents as the demand for air travel increases, simply due to the increase in exposure to hazards. Mathematics makes it clear that a steady accident rate combined with an increase in traffic means an increase in the number of accidents. Since there is every indication that commercial air travel will continue to increase, we must do something as an industry in order to continue to decrease the accident rate so that we do not increase the number of accidents.

Fortunately, human ingenuity has figured out that we do not have to have

accidents in order to prevent them. At the heart of an accident is a series of hazards, previously only unmasked through accident investigation. Those same hazards can be unveiled through observation and analysis techniques known collectively as *proactive safety*. This term means that we can identify hazards that may not be obvious before the hazard triggers an accident. Proactive safety is often used in contrast to similar terms, such as *reactive safety* (accident investigation), *active safety* (making real-time decisions based on obvious hazards), and *predictive safety* (determining how the future may produce new hazards). The predictive safety approach will be covered more thoroughly in our discussion of the emerging panorama of safety in Chapter 14.

This chapter showcases the most commonly used proactive aviation safety programs that help detect and measure hazards. Some of the programs can be used in stand-alone fashion, but the use of all programs together brings maximum hazard detection and provides the best chance of preventing accidents and serious incidents.

FLIGHT OPERATIONAL QUALITY ASSURANCE (FOQA)

The first proactive aviation safety program featured entails taking quantitative (numbers) flight data from routine operations and using the data to detect hazards. Depending on the part of the world and personal preference, this program may be called *Flight Operational Quality Assurance (FOQA)*, *Flight Data Monitoring (FDM)*, or *Flight Data Analysis (FDA)*. Some airlines even use their own specialized term. For example, the process is described as the Flight Data Analysis Program (FDAP) at Southwest Airlines.

The term *FOQA* is preferred in the United States, whereas much of the world refers to the program as FDM. Some dislike the word *monitoring* in FDM because they believe it connotes the scrutiny of crewmember actions, and therefore, many favor the word *analysis* in FDA. Although the processes used for these methods of data collection are similar, the difference in terms also has additional meaning. In the United States, airline participation in a FOQA program is strongly recommended but is still voluntary. For non-U.S. operators, ICAO requires that airlines operating aircraft that have maximum takeoff weights over 59,500 pounds participate in FDM.

Regardless of what we call it, the concept entails the analysis of routine flight data to enable early intervention to correct adverse safety trends before they lead to accidents. The process also provides an objective means for validating the effectiveness of corrective actions after they are implemented. Routine flight

data refers to the numerical data pertinent to everyday, non-accident flights and the measurements of specific parameters, such as airspeed, configuration, and bank angle. These data are then compared against present parameters to determine how closely flights are coming to preset safety limits. Today, FOQA programs have grown in sophistication and are powered by highly capable recording devices that can capture thousands of flight parameters. Figure 7-1 illustrates a flight deck picture showing control movements, engine settings, automation modes, and aircraft performance measures, all of which can be captured through different types of flight data recorders for later analysis.

FIGURE 7-1 Instrument readings and control inputs are routinely captured for FOQA analyses. (*Source: Wikimedia Commons*)

The road to FOQA has actually been quite long, considering that the powered-flight industry is not much more than a century old. In 1958, the aviation industry produced minimum specifications for flight data recorders (FDRs). Although a few other airlines were early adopters of the FOQA concept, much credit goes to British Airways for commencing a robust initiative in 1962 with the Trident fleet of aircraft. Around 1985 solid-state memory cards started replacing the magnetic tapes of FDRs and allowing for easier data access. The framework for a modern FOQA program began in the late 1980s by the Flight

Safety Foundation. Their plan for the program has served as the backbone for FOQA progress in the United States.

In 1990, the FAA took the initiative to develop FOQA program guidance by hosting a workshop. In the mid-1990s, the FAA started vocally proposing the FOQA concept. In 2001, the FAA developed a rulemaking committee to formalize work in this area. The committee convened from 2001 until 2005, making significant progress and decisions about the development during that time. In 2004, the Voluntary Safety Programs Branch AFS-230 of the FAA released Advisory Circular 120-82. This detailed the recommended procedures to be followed for the establishment of a FOQA program for commercial operators.

As part of determining the process, the FAA conducted a pilot run to assess the costs, benefits, and safety enhancements possible through FOQA. They provided software and hardware to four airlines who agreed to start FOQA programs and to share the data with the FAA. The FAA determined that FOQA programs would be voluntary, as data collection and use for advancement was still in the early stages. The project revealed that the use of FOQA in an airline environment could enhance trend monitoring and the identification of operational risks. On an international level, in 2008 ICAO amended the Annex 6 mandate to introduce requirements and recommendations for safety management and safety management systems, including the adoption of FDMs by all non-U.S. airlines.

There are several key pieces of technology, both hardware and software, that are widely used for gathering or processing the data needed for the FOQA program. They include the following:

- *Flight Data Acquisition Unit (FDAU)*. This device acquires aircraft data through a digital data bus and analog inputs. The FDAU formats the data for output to a flight data recorder in accordance with requirements of regulatory agencies. Many FDAUs have a second processor and memory module that enables them to perform additional Aircraft Condition Monitoring System (ACMS) functions/reports. The FDAU can provide data and predefined reports to the cockpit printer, directly to Aircraft Communications Addressing and Reporting System (ACARS) for transmittal to the ground, or to a Quick Access Recorder (QAR) for recording/storage of raw flight data. The FDAU can also display data for the flight crew.
- *Data Management Unit (DMU)*. This device performs the same data conversion functions as a FDAU, with the added capability to process data

onboard the aircraft. Additionally, this unit has a powerful data processor designed to perform in-flight airframe/engine and flight performance monitoring and analysis. Some DMUs have a ground data link and ground collision avoidance systems incorporated into the unit.

- *Ground Data Replay and Analysis System (GDRAS)*. It is a software application used by safety analysts on the ground, designed to transform airborne-recorded data into a usable form for analysis. It also processes and scans selected flight data parameters, compares recorded or calculated values to predetermined norms using event algorithms, and generates reports for review.
- *Quick Access Recorder (QAR)*. It is a device onboard some aircraft that stores flight-recorded data but that is not crash-survivable. These units are designed to provide quick and easy access to a removable medium, such as a flash memory card, on which flight information is recorded. QARs may also store data in solid-state memory that is accessed through a download reader. QARs have now been developed to record an expanded data frame, sometimes supporting over 2,000 parameters at much higher sample rates than the flight data recorder. The expanded data frame greatly increases the resolution and accuracy of the ground analysis programs.

One of the most labor intensive and costly aspects of a FOQA program is determining and implementing the process for retrieving the data from the aircraft onboard recording system to the GDRAS. Items to consider are removing the recording medium from the plane and forwarding the data to the GDRAS location for analysis. Consider that some airlines have thousands of flights per day, which requires an efficient and consistent means for data recording and retrieval. For flight data that is recorded with hardware on the plane, such as some of the devices mentioned above, an operator’s line maintenance department will most likely remove the medium during a scheduled overnight maintenance. Then, personnel must send the data back to the air carrier’s FOQA office for analysis and will do so either by mail, electronically, or wirelessly. Such is often the process when the data comes from traditional crash survivable FDRs, as shown in Figure 7-2.

FIGURE 7-2 A crash survivable FDR can also be used for FOQA. (*Source: Authors*)

Once the data arrives at an airline's FOQA office and is prepared in an appropriate format, it is ready for analysis. A skillful analyst using specialized software can extract safety events from the raw digital data stream based on parameters, threshold values (e.g., descent rate in excess of 1,000 feet per minute on approach), and/or routine operational measurements that are specified by the air carrier. Data that could be used to determine flight or crewmember identities are removed from view in the electronic record as part of the initial processing of airborne data. However, air carrier FOQA programs usually have a *gatekeeper*, who is provided with a secure means for maintaining identifying information for a limited period of time. This measure enables follow-up inquiry with the specific flight crew associated with a particular event if necessary.

Analyses may focus on events that fall outside normal operating boundaries, event categories, or as determined by the air carrier's operational standards and manufacturers' aircraft operating limitations. A FOQA monitoring team then reviews the events to assess their potential significance. Lastly, FOQA events are marked for appropriate handling to pinpoint the potential source of the problem and suggest an appropriate corrective action. Figure 7-3 shows an aircraft maneuvering for landing and illustrates the crucial safety concept of flying a stabilized approach to ensure a safe landing. Given that the approach

and landing are often the most critical phases for commercial aviation operations, FOQA programs commonly set up parameters for measuring approach stability. A single unstable approach may get a FOQA analyst's attention, but if a series of unstable approaches are detected at a specific location or with a certain type of aircraft, it is almost certain that a safety problem exists that requires further investigation.

FIGURE 7-3 FOQA provides scientific analysis of data important to a stabilized approach. (*Source: Wikimedia Commons*)

AVIATION SAFETY ACTION PROGRAM (ASAP)

The goal of *Aviation Safety Action Program (ASAP)* is to prevent accidents and incidents by identifying unsafe practices and correcting them through individual written submissions from employees. It encourages the voluntary reporting of safety issues by the rank-and-file people involved in everyday operations. Under

ASAP, safety issues are resolved through corrective action rather than through punishment or discipline. The program's strategy is to create a nonpunitive environment through incentives for employees to report safety issues, even though these issues may involve an alleged violation of aviation regulations.

The origins of ASAP stem from the FAA's desire to prevent the recurrence of the same types of accidents. Toward that end the FAA collaborated with industry in the 1990s to establish several demonstration ASAPs to explore how safety information could be shared within and between air carriers. Programs were established in USAir, American Airlines, and Alaska Airlines and the results were successful. In 1997, the FAA issued an ASAP Advisory Circular to promote the initiative even further.

With an ASAP, an airline enters into a safety partnership with the FAA and may include a third party such as the employee's labor union. Information contained in ASAP reports may be considered sensitive by some airlines. To address the concern about disclosure of sensitive information, the FAA takes strong confidentiality measures to protect ASAP reports and other sensitive safety and security information from being disseminated to the public.

When someone experiences a safety-related event or detects a hazard, they are encouraged to submit a written account to the operator's ASAP committee about the event and how it involves an operational or maintenance issue. Submissions should describe the situation in enough detail so that it can be evaluated by a third party. Employees can submit the problem electrically through a web-based ASAP report form, which may even be accessible from an employee's home. Many places also have a hotline employees can use if an online report is inaccessible.

Aviation Safety Action Program provides a voluntary and cooperative environment for the open reporting of flight safety concerns. Information obtained from an ASAP report should not be used for disciplinary action, unless the employee has intentionally committed a violation of law or regulations. This protective provision is important because employees are more likely to report problems if they know they will not be penalized for their "human error" mistakes. In organizations with low employee-management trust, sometimes there is a fear that management will use the information provided in the ASAP report to discipline the employee who reported his or her error. However, all participating companies explicitly agree not to use information gained from a report for corrective purposes.

An *Event Review Committee (ERC)* periodically meets to review ASAP reports. The ERC is commonly composed of two people from each of the

following groups: the company (management), employees, and the regulator (the FAA in the United States). Their duty is to review and analyze reports submitted under the ASAP, determine whether such reports qualify for inclusion in the program, identify actual or potential problems from the information contained in the reports, and propose solutions for those problems. (See FAA Advisory Circular 120-66B for full guidance regarding ASAP.)

A successful ASAP cannot flourish under just any conditions. Instead, companies must also have a robust safety culture that promotes behaviors and attitudes related to safety for the program to thrive. There must also be a strong sense of trust between employees and managers, as there is sometimes fear that management will use the information from the ASAP reports to punish employees. Companies should also align their ASAP goals with the organizational safety goals in their SMS to reflect their commitment to the program.

Different employee groups at an airline can participate in ASAP. Some ASAPs allow submissions not just from pilots but also from dispatchers, flight attendants, aviation maintenance technicians, and other key players in the safety value chain for any given operation. For example, air traffic controllers have a similar program called the *Air Traffic Safety Action Program (ATSAP)*. ATSAP is also nonpunitive and encourages controllers to identify and report all events that have had an impact on air traffic control safety.

Just like ASAP, the ATSAP provides safety data that would otherwise never be reported without the use of nonpunitive, voluntary participation. Such reports submitted ultimately help in identifying the root causes of safety breakdowns and determine the appropriate corrective action. Figure 7-4 shows controllers at work at the Anchorage Air Route Traffic Control Center. An ATSAP analyst looking at that figure would see each person pictured in the control room as a potential means for uncovering operational safety hazards.

FIGURE 7-4 ATSAP allows air traffic controllers to voluntarily report safety hazards. (*Source: Wikimedia Commons*)

AVIATION SAFETY REPORTING SYSTEM (ASRS)

Somewhat similar to the previously discussed ASAP is the *Aviation Safety Reporting System (ASRS)*. The ASRS an extremely successful joint effort by the FAA and NASA to provide a voluntary reporting system where pilots, controllers, flight attendants, aviation maintenance technicians, and others in the industry can submit anonymous accounts of safety-related aviation incidents. While ASAP data sometimes remain local to an operation and visible only to those in a given company, ASRS contains global data (although mostly with data collected in the United States) and can be accessed by anyone. The system was initially launched by the FAA, which quickly recognized that their regulatory and enforcement roles would discourage the aviation community from using this

new safety program that depended on voluntary sharing of safety events. Therefore, the FAA turned the program over to NASA, a neutral and highly respected third party, to collect, process, and analyze the voluntarily submitted reports. Under a Memorandum of Agreement between the two agencies in August 1975, the plan for operating the newly designated ASRS was set in place. It detailed that the FAA would fund the program and provide for its immunity provisions, while NASA would set program policy and administer operations. The majority of the data comes from people working for the airlines.

Aviation Safety Reporting System funding primarily comes from the FAA, while it is administered by NASA and maintained by Battelle Laboratories. Reports are sent to the ASRS office at NASA Ames Research Center, where the data are analyzed and entered into a computer by employees of Battelle. Data from the reports are used to:

- Identify problems in the National Airspace System so that they can be resolved by appropriate authorities.
- Develop policy, planning, and improvements to the National Airspace System.
- Fortify the foundation of human factors safety research in the aviation field.

As discussed earlier in this book, progress in safety has sadly come at the expense of human life being lost. The creation of the ASRS is no exception. On December 1, 1974, TWA Flight 514 was inbound to the Dulles Airport in a cloudy and turbulent sky. The flight crew misunderstood the clearance from air traffic control and descended into a Virginian mountaintop, killing everyone on the plane.

Findings from the accident investigation revealed that 6 weeks earlier, a United Airlines flight crew had experienced the same clearance misunderstanding and only narrowly missed hitting the same terrain in Virginia during a nighttime approach. A warning notice had been issued to all United Airlines pilots, but at the time, there was no method for sharing information among pilots in different airlines. After this, it was concluded that future safety information must be shared among the entire aviation community. The first step in establishing a national aviation incident reporting program was to design the ASRS system in which everyone could place a high degree of trust.

Today, ramp agents, aviation maintenance technicians, flight attendants, air traffic controllers, pilots, and any other professionals involved in aviation operations can submit reports to the ASRS when they observe or are involved in

an incident or situation involving a breakdown of safety. All submissions are voluntary and are held in strict confidence. According to ASRS, more than a million reports have been submitted to date and not even one reporter's identity has ever been breached. This is because ASRS de-identifies reports before they are entered into the database. All personal and organizational information is removed, while dates, times, and related information that could be used to guess someone's identity are either generalized or eliminated. This feature of anonymity is important as the program is forbidden to use ASRS information for enforcement actions. Through this program and the guarantee of identity protection, the FAA can demonstrate the value it places on the safety information gathered through incident reporting to the ASRS. Figure 7-5 illustrates the appearance of the web interface that is used by reporters when submitting safety incidents to the ASRS. Figure 7-6 shows an actual ASRS narrative that has been inserted into the input field of the web-based form to show how it appears when in use by an aviation maintenance technician.

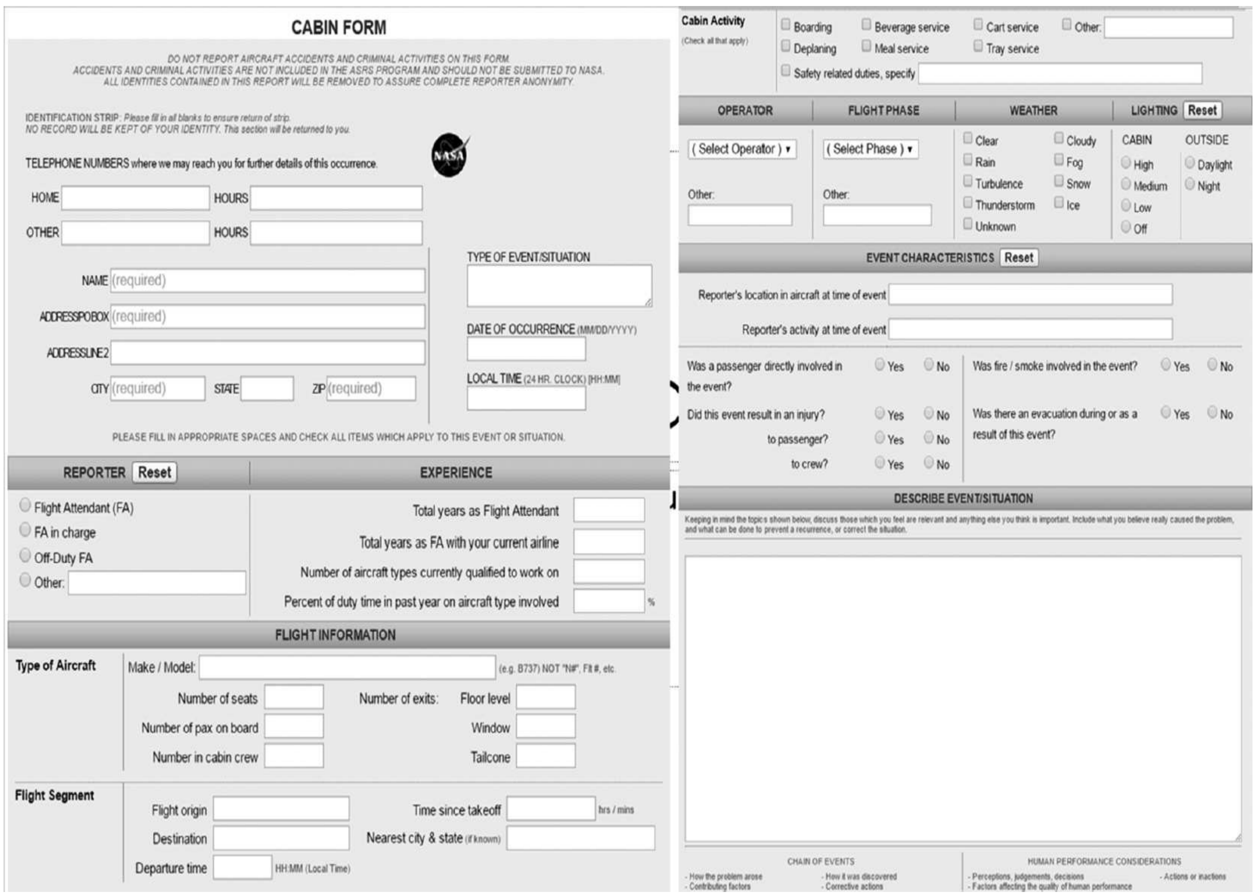
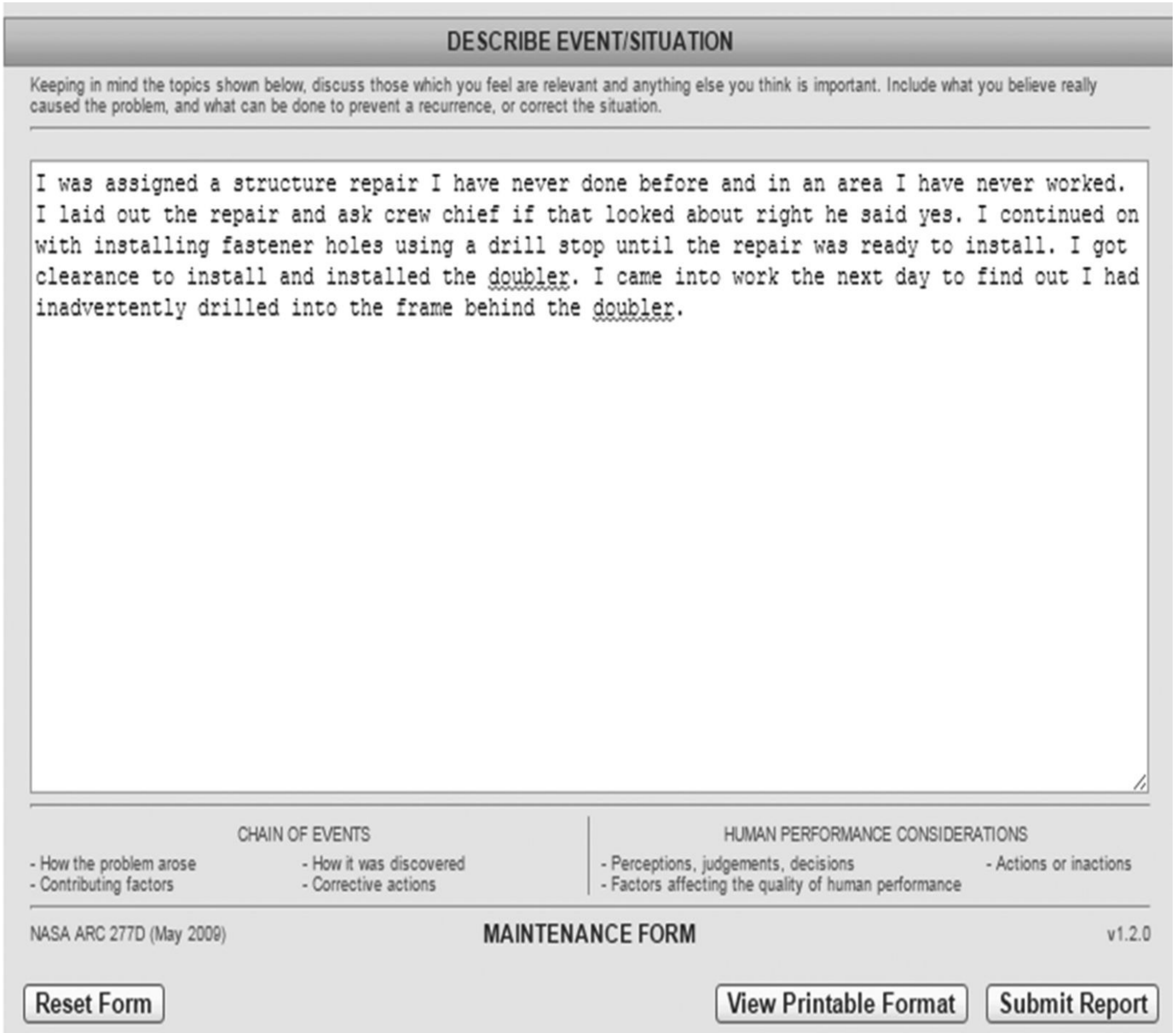


FIGURE 7-5 Sample ASRS database web interface with fields for reporters to furnish aviation safety information. (*Source: NASA*)



DESCRIBE EVENT/SITUATION

Keeping in mind the topics shown below, discuss those which you feel are relevant and anything else you think is important. Include what you believe really caused the problem, and what can be done to prevent a recurrence, or correct the situation.

I was assigned a structure repair I have never done before and in an area I have never worked. I laid out the repair and ask crew chief if that looked about right he said yes. I continued on with installing fastener holes using a drill stop until the repair was ready to install. I got clearance to install and installed the doubler. I came into work the next day to find out I had inadvertently drilled into the frame behind the doubler.

CHAIN OF EVENTS

- How the problem arose
- Contributing factors
- How it was discovered
- Corrective actions

HUMAN PERFORMANCE CONSIDERATIONS

- Perceptions, judgements, decisions
- Factors affecting the quality of human performance
- Actions or inactions

NASA ARC 277D (May 2009) MAINTENANCE FORM v1.2.0

Reset Form View Printable Format Submit Report

FIGURE 7-6 The ASRS database contains detailed reports from aviation maintenance technicians, among other aviation professionals. (*Source: Authors*)

Once the report has been submitted, it goes to the ASRS staff to be analyzed. The ASRS staff includes highly experienced aviation professionals who have backgrounds as pilots, air traffic controllers, aviation maintenance technicians, and managers. After reports have been submitted and stripped of identifying information, they are read by a minimum of two aviation safety analysts. Their first objective is to identify any aviation hazards that require immediate action. When identified as such, an alerting message is sent to the appropriate FAA office or aviation authority. The second goal of the analysis is to classify reports and determine the underlying causes of the event. The safety analysts' observation and the original report are then entered into the ASRS database.

To share the findings with the aviation community, ASRS has several publications and studies they release. *CALLBACK* is a monthly safety newsletter that shares de-identified ASRS reports with a commentary on the events. Another communication tool is *ASRS Directline*, which targets operational managers, safety officers, and training organizers. The publication contains articles based on ASRS reports that have been deemed significant by ASRS analysts. Lastly, ASRS occasionally conducts research on safety topics suggested by the FAA or aviation companies. The goal of this research is to address real-life aviation safety issues and improve human performance in the complex National Airspace System.

LINE OPERATIONS SAFETY AUDIT (LOSA)

A *Line Operations Safety Audit (LOSA)*, which is sometimes called an *assessment* versus an audit, describes a voluntary, formal process that uses highly trained observers to collect safety-related data on regularly scheduled flights. Initial research on LOSAs was developed during a joint effort between FAA, Continental Airlines, and the University of Texas at Austin.

The Line Operations Safety Audit involves an observer, often a trusted airline captain, who rides in the jumpseat in the flight deck of an aircraft to annotate data about flight crew behavior. He or she also aims to assess crew strategy for managing threats and errors under conditions of operational complexity. These threats and errors are part of everyday operations that crewmembers must manage to maintain flight safety. ICAO also promotes the importance of LOSA to the international aviation community in its Line Operations Safety Audit Manual.

Since LOSA's primary objective is to identify strengths and weaknesses during normal flight operations, observations occur on regularly scheduled flights. The observer, often times a peer, is only collecting safety data, not evaluating or debriefing the flight crew. Observations are conducted with a guarantee of confidentiality and the assumption that action will not be taken against the crew for its performance during the flight. Acting as a "fly on the wall," the evaluator can use the LOSA Observation form, which is based on the University of Texas Threat and Error Management (TEM) Model, or an airline-specific form to analyze systematic factors that can affect flight crew performance. Observers record the threat and error events that they see or hear and then write narratives that include contextual support. (See FAA Advisory Circular 120-90 to learn the rationale and procedures for performing a LOSA at an airline.)

an airline.)

To ensure confidentially, there is a third-party or a pilot association that provides personnel to act as gatekeepers. The data is then checked for coding accuracy and consistency with standard operating procedures through a data cleaning roundtable. Once data are cleaned and validated to ensure that they match airline operations, they are analyzed by someone who has knowledge about the airline’s flight operations. An airline might choose a third-party analyst if pilots have expressed concern about the integrity of the LOSA implementation. The analysis of trends in the data can reveal the airline’s operational strengths and weaknesses as a whole, versus the individual situations that are described through ASAP and ASRS submissions.

Line Operations Safety Audit analysts will investigate the prevalence and management of different events and errors that occur. Patterns that surface can show that certain errors occur more frequently than others, specific airports may be more problematic than others, and some standard operating procedures are routinely modified or ignored. These findings then serve as the cornerstone for creating change. Two to three years later, a follow-up LOSA can be performed to follow-up on previous safety initiatives in order to measure if an airline’s changes have resulted in improved performance.

Once the analysis is complete, a LOSA report is written to communicate the findings from the audit. It includes information about what the airline should target to enhance the safety of operations. Both management and pilots will receive briefings about the results, and changes will be implemented to mitigate potential problems. Pilots may receive the information from a LOSA debriefing event, airline newsletter, or other safety periodicals.

Although LOSA started as a safety program geared toward pilots, it has also evolved to include maintenance and ramp operations. Capitalizing on the success of LOSA, the development of these maintenance and ramp LOSA programs was conducted under the auspices of the Airlines for America (A4A) industry association.

ADVANCED QUALIFICATION PROGRAM (AQP)

By the late 1980s, human error had been increasingly highlighted as one of the largest factors in accidents among air carriers in the Unites States. The FAA and industry agreed that there needed to be more flexible training regulations that would allow for a more creative response to the threat of human error. As a result, the FAA modified a successful CRM military training method that combined front-end task analysis with backend data analysis to create the

Advanced Qualification Program (AQP) training program.

The AQP is a voluntary alternative to the traditional regulatory requirements for pilot training and assessment under 14 CFR Parts 121 and 135 that have formed the bedrock of airline training programs for decades. The goals of AQP are to increase aviation safety through improved training and evaluation and to be responsive to changes in aircraft technology, operations, and training methodologies. It is a process to qualify, train, certify, and assure that dispatchers, pilots, and flight attendants are competent using Crew Resource Management (CRM) techniques. (See FAA Advisory Circular 120-54A for guidance on obtaining approval for an AQP.)

The principle of AQP is to have the specific requirements of piloting a given aircraft at a specific airline determine the content of training and checking activities instead of simply making those activities generic for all airline pilots. The first step in AQP is conducting an aircraft-specific job task analysis, which begins with the development of a comprehensive list of each crewmember position. The list should cover items internal to the aircraft, external to the aircraft, normal, abnormal, and emergent issues. Essentially, it should cover everything a pilot may be exposed to within the sphere of operations. AQP analyses identify skills that are found to be applicable across multiple flight tasks. Additional analyses can be used to develop guidelines for the frequency of occurrence in routine operations, operational criticality, and success criteria.

AQP differs from traditional regulatory requirements in a number of ways:

- Participation is voluntary. If an air carrier chooses not to participate, it will continue to be governed by 14 CFR Parts 121 or 135.
- An AQP can employ innovative training and qualification concepts as long as it meets the same objectives as FAA’s traditional training programs.
- AQP involves proficiency-based qualification. Pilots are trained to a standard of proficiency on all objectives within an approved AQP curriculum. Proficiency evaluation may consist of items that validate competencies in outlined objectives. Each air carrier applicant, rather than the FAA, develops its own objectives that provide an approved means for the carrier to propose additions, deletions, or changes as needed to maintain a high degree of aircrew proficiency tailored to the operator’s line requirements.

Ultimately, this method allows for the collection of performance data on students, instructors, and evaluators which are then used for curriculum refinement and validation. AQP can be tailored to include both specific training for instructors and evaluators and explicit training and evaluation strategies for

verifying the proficiency and standardization of CRM crew-oriented, scenario-based training and assessment tasks.

AVIATION SAFETY INFORMATION ANALYSIS AND SHARING (ASIAS)

The FAA *strongly* promotes the open exchange of safety information in order to continually improve aviation safety. As a part of this philosophy, the FAA developed the *Aviation Safety Information Analysis and Sharing (ASIAS)* system to allow for collaborative data sharing and analysis between government and industry.

As noted on the FAA web page, the ASIAS program connects approximately 185 data and information sources across government and industry, including voluntarily provided safety data. The ASIAS program works closely with the Commercial Aviation Safety Team (CAST) and the General Aviation Joint Steering Committee (GAJSC) to monitor known risk, evaluate the effectiveness of deployed mitigations, and detect emerging risk.

Aviation Safety Information Analysis and Sharing is truly growing in size and scope every day. There are currently 45 Part 121 member air carriers, 20 corporate/business operators, two manufacturers, and two maintenance, repair, and overhaul organizations participating in ASIAS. The program continues to evolve but has matured to the point that the Federal Aviation Administration (FAA) and industry can leverage voluntarily provided safety data from operators that represent 99% of U.S. air carrier commercial operations. The ASIAS database includes detailed records of some 20 million flights across U.S. airspace; roughly 200,000 incident reports voluntarily submitted by pilots; and roughly 100,000 voluntary reports from air traffic controllers. It has been reported that on average pilots file over 4,000 new reports each month.

Aviation Safety Information Analysis and Sharing also partners with the industry-sponsored Aviation Safety InfoShare meeting, which facilitates the sharing of Part 121 safety issues and best practices in a protected environment. This partnership enables ASIAS to provide a data-driven approach to early identification of emerging systemic safety issues within the National Airspace System (NAS).

Aviation Safety Information Analysis and Sharing retains access to a wide variety of public and proprietary data sources. Each source provides information from different parts of the NAS. Current examples of ASIAS sources include the following (www.faa.gov):

- ACAS (AirCraft Analytical System)
- ASAP (Aviation Safety Action Program)
- ASDE–X (Airport Surface Detection Equipment–Model X)
- ASPM (Airspace Performance Metrics)
- ASRS (Aviation Safety Reporting System)
- ATSAP (Air Traffic Safety Action Program)
- FOQA (Flight Operational Quality Assurance)
- METAR (Meteorological Aviation Report)
- MOR (Mandatory Occurrence Reports)
- NFDC (National Flight Data Center)
- NOP (National Offload Program office track data)
- SDR (Service Difficulty Reports)
- TFMS (Traffic Flow Management System)

Under the Code of Federal Regulations, all ASIAS data are protected from the Freedom of Information Act and safeguard voluntarily supplied reports. MITRE, the operating entity of ASIAS, also is exempt from the Freedom of Information Act. Furthermore, the FAA received re-authorization from Congress to protect data that support SMS programs and studies for metrics and safety analysis. Under these exemptions, aviation professionals feel that they can share information that will create a safer operating environment.

The FAA is increasing the quantity and types of ASIAS participants as part of a phased expansion plan, such as expanding participation in the corporate/business and small general aviation communities. It will also expand into the rotorcraft and unmanned aircraft systems communities in the future.

GENERAL INDUSTRY (OSHA) RECORDING AND REPORTING SYSTEMS

APPLICABILITY

As previously stated in Chapter 5, the mission of OSHA is to assure safe and healthful working conditions for working men and women. In order to “keep score” in a proactive environment, OSHA has basic employer reporting requirements.

OSHA regulations listed in 29 CFR 1904 require every employer covered by

the OSHA Act with 11 or more employees to record and report all employee occupational (work-related) deaths, injuries, and illnesses on OSHA Forms 300 and 301. Employers with 10 or fewer employees are required to keep injury and illness records only if OSHA or the Bureau of Labor Statistics (BLS) specifically notifies them in writing that they must keep these records. However, all employers covered by the OSHA Act must report all deaths and events that cause in-patient hospitalization of three or more employees to OSHA (in person or via phone to the OSHA area or central office) within 8 hours of being aware of the events. Injuries and illnesses that require only first aid are exempt from being recorded. Injuries include, but are not limited to, cuts, fractures, sprains, or amputations. Illnesses include both acute and chronic illnesses such as skin disease, respiratory disorder, or poisoning.

Injury and illness records are used for several purposes. OSHA collects data through the *OSHA Data Initiative* (ODI) to help direct its programs and measure its own performance. Inspectors also use the data during inspections to help direct their efforts to the hazards that are hurting workers. Records are used by employers and employees to implement safety and health programs at individual workplaces. Analysis of the data is a widely recognized method for discovering workplace safety and health problems and for tracking progress in solving those problems. Records also provide the base data for the BLS Annual Survey of Occupational Injuries and Illnesses, the nation’s primary source of occupational injury and illness data. Each year, the BLS uses a stratified random data collection survey process to collect injury and operational data (e.g., hours worked) from companies across the United States. It then analyzes, categorizes, and publishes the data by industry groupings called standard industrial classification (SIC) codes. Companies can use these data to compare themselves to their peer industries.

OSHA Form 300: Log of Work-Related Injuries and Illnesses

This form is used by employers to record occupationally related injuries and illnesses other than first aid and requires the following information:

- Employee’s name, employee’s job title, date, and the place (department) where the injury/illness occurred.
- A very short description of the injury/illness, including the body part that was affected and what caused it.
- The number of lost or restricted workdays that the injury/illness caused.

- The type or classification of the injury/illness.

OSHA Form 301: Injury and Illness Incident Report

This incident report Form 301 contains more detailed information on the injuries/illnesses than that listed in Form 300. Every injury or illness listed in Form 300 must have an accompanying Form 301. Information on Form 301 describes in greater detail how the injury or illness occurred, what time of day it happened, what the employee was doing when he or she was injured, and the extent of medical treatment the injury or illness required. Actual copies of *OSHA Forms 300 and 301* can be downloaded from the OSHA Web site (www.osha.gov). Note that the FAA uses the Mishap Report Form 3900-6 (or succeeding form) for its own internal facilities and operations.

OSHA Form 300A: Summary of Work-Related Injuries and Illnesses

Employers ensure that the Occupational Safety and Health Administration Form 300A, the annual summary of illnesses and injuries form, and the OSHA Form 301 incident report are retained on file for 5 years following the end of the calendar year that these records cover (29 CFR 1904.33). An employer is required to post a summary (*OSHA Form 300A*) of the total number of injuries and illnesses for the (calendar) year in an easily accessible and visible place (preferably on the employee bulletin boards) at each establishment. Totals for the previous year must be displayed continuously from February 1 through April 30 of the year following the year covered by the form.

Open Government Initiative (Transparency in Government)

Occupational Safety and Health Administration will be implementing a new, improved, and modernized recordkeeping system which will be made public to encourage innovative ideas in improving occupational safety and health.

The final rule, which took effect in 2017, requires records of workplace injuries and illnesses to be submitted to OSHA electronically. OSHA will post the establishment-specific injury and illness data it collects on its public Web site while removing any personally identifiable information. The data release in standard open format is intended to encourage employers to prevent/reduce workplace injuries and illnesses as they will be able to benchmark their safety and health performance against industry leaders.

In addition, public access to very large sets of injury and illness data will

enable public health researchers to analyze the data in ways that could help employers make their workplaces safer by identifying occupational hazards before they lead to injuries, advance the fields of injury and illness causation, and conduct prevention research. Additional information on this is available at www.osha.gov.

ENVIRONMENTAL RECORDING AND REPORTING

As stated in Chapter 5, the mission of the Environmental Protection Agency (EPA) in the United States is to protect human health and the environment. At first glance it may seem puzzling to include environmental issues in a book on commercial aviation safety, until one realizes that the environment directly impacts the conditions for life, and therefore, can be considered a safety issue. Such a thought is particularly true when we grasp the notion that commercial aviation operations can have a direct impact on the environment. Under federal environmental laws, any facility or vessel (e.g., oil spills from ships) must report to government authorities about any hazardous substance that is released into the environment in quantities that exceed a threshold amount.

In commercial aviation safety, such situations will often involve airport operations. Threshold amounts are referred to as *reportable quantities (RQs)* and must be reported in a timely manner as determined by state statutes and federal government requirements. For example, safety managers involved with airport operations must produce reports when threshold amounts are reached in accordance with numerous federal government acts, such as the following:

- The *Clean Water Act (CWA)*
- The *Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)*, also known as the Superfund
- The *Emergency Planning and Community Right-to-Know Act (EPCRA)*
- *The Resource Conservation and Recovery Act (RCRA)*
- *The Toxic Substances Control Act (TSCA)*

The environment can include air, water, soil, or a combination of these three media. A release includes any contact of a hazardous substance with the environment through either intentional or unintentional discharge and by any method (e.g., spilling, leaking, dumping, leaching, and abandonment of barrels or other closed containers containing hazardous substances). Notification of releases is usually required immediately or within 24 hours of knowledge of the

release. EPA regulations cover a variety of reporting requirements that include the following:

- Medium environments into which the release is applicable
- Listing of hazardous substances together with their quantities
- Persons responsible for reporting
- Time line for reporting
- The agency to contact in case of a release
- Fines for not reporting

In some cases there is also a requirement for follow-up reporting which must include the original notification, response actions taken, acute or chronic health risks associated with the release, and advice on medical care to exposed victims.

All these reporting release requirements help ensure accountability for cleanup; provide data for regulatory and public policy purposes; and enable federal, state, and local authorities to effectively prepare for and respond to emergencies that could harm humans and the environment. The EPA does not necessarily take enforcement action against releasers but it is quite strict against those violators who fail to report releases.

OTHER ENVIRONMENTAL REPORTING REQUIREMENTS

Other regulations (in addition to CERCLA and EPCRA) may also require reporting the release of hazardous materials. These reports will often be associated with operations at airports that support commercial aviation traffic. Some of these are as follows:

- The *Hazardous Materials (HAZMAT) Transportation Act (HMTA)* requires reporting hazardous material released during shipping and handling. These regulations are administered by the Department of Transportation (DOT).
- The Toxic Substances Control Act (TSCA) requires reporting the releases of polychlorinated biphenyls (PCBs) and also addresses asbestos-, radon-, and lead-based paint.
- The Clean Water Act (CWA) requires reporting of hazardous substances listed under 40 CFR 116.4 and oil releases from vessels and facilities into navigable waters.
- Hazardous wastes listed in the Resource Conservation and Recovery Act

(RCRA) under 40 CFR Part 261, Subpart D, and characteristic wastes under 40 CFR Part 261, Subpart C are reportable if the release equals or exceeds the designated reportable quantity.

CONTROL OF AIR POLLUTION FROM AIRCRAFT AND AIRCRAFT ENGINES

As stated in Chapter 5, air pollution from aviation turbine and piston engines remains a continuing health issue. The sections within applicable EPA regulations (40 CFR Part 87) deal with setting limits on exhaust emissions of smoke from aircraft engines, ban venting of fuel emissions into the atmosphere from certain types of aircraft engines, and require the elimination of intentional discharge to the atmosphere of fuel drained from fuel nozzle manifolds after engines are shut down. The EPA and FAA are also proactively reviewing new regulations regarding lead emissions from piston engine aircraft using AVGAS. Current information is available on www.epa.gov and www.faa.gov.

CONCLUSION

The crash of TWA Flight 514 near Dulles Airport in 1974 brought home the fact that safety information must be shared freely and frequently in order to prevent accidents from happening due to hazards that are known by others. The TWA crash helped create a system for sharing hazard information which today is one of several proactive systems that have been established for similar purposes.

Flight Operational Quality Assurance is a quantitative system that is excellent at exposing what types of hazards exist but not necessarily why they exist or how the hazards function against us as part of the overall operational context. ASAP and ASRS get directly into the minds of reporters, and as such, are excellent at explaining why hazards and errors exist but these tools are not good at quantifying the frequency of the situations or the context. LOSA is a wonderful tool for exposing the context from which threats and errors arise but it does not quantify exposure across an entire operation and sometimes cannot get inside the mind of those being observed. Obviously, the ideal approach for proactive safety is one where multiple programs are simultaneously leveraged. In so doing, FOQA can tell us how frequently we encounter an unsafe condition, voluntary reporting can tell us why specific hazards arise, and LOSA can depict the overall context. These data sources can then be fed into an AQP training program that custom-tailors training to existing conditions. The ASIAS “big data” storage and retrieval system is the comprehensive means the FAA uses to work across boundaries.

Safety is obviously a priority in the aviation industry. We cannot be blind to our surroundings and must constantly have our eyes open to dangers that exist around us. When we do see or experience something that could have an adverse effect on safety, it is our duty as aviation professionals to report the incident in an effort to prevent it from happening again. De-identifying information about safety breakdowns greatly assists the effort, since aviation professionals are more likely to submit narratives when they know they will not be disciplined for making human errors.

Another important common thread that is woven throughout this chapter is the idea of information sharing through full collaboration. Creating safer operations is a team effort when everyone is working toward the same goal. Every player in the aviation community must be willing to contribute to these proactive communication systems if they truly want to improve commercial aviation safety for all.

KEY TERMS

Active Safety
Advanced Qualification Program (AQP)
Air Traffic Safety Action Program (ATSAP)
Aviation Safety Action Program (ASAP)
Aviation Safety Information Analysis and Sharing (ASIAS)
Aviation Safety Reporting System (ASRS)
Clean Water Act (CWA)
Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)
Data Management Unit (DMU)
Emergency Planning and Community Right-to-Know Act (*EPCRA)*
Event Review Committee (ERC)
Flight Data Acquisition Unit (FDAU
Flight Operational Quality Assurance (FOQA)
Gatekeeper
Ground Data Replay and Analysis System (GDRAS)
Hazardous Materials (HAZMAT) Transportation Act (HMTA)
Line Operations Safety Audit (LOSA)
OSHA Data Initiative
OSHA Form 300

OSHA Form 300A
OSHA Form 301
Predictive Safety
Proactive Safety
Quick Access Recorder (QAR)
Reactive Safety
Reportable Quantities (RQs)
Resource Conservation and Recovery Act (RCRA)
Toxic Substances Control Act (TSCA)

REVIEW QUESTIONS

1. Explain why we can expect more accidents in the future if we continue with the same current accident rate.
2. Which reporting method described in this chapter do you think can make the biggest impact on safety? Defend your answer.
3. How does FOQA contribute to creating a proactive safety environment?
4. Why does the ERC play an important role in ASAP?
5. Describe how ASRS can be described as a collaborative approach to safety.
6. If your pilot colleagues were hesitant to allow an observer collecting data for LOSA to ride their jumpseat on a flight, how would you convince them otherwise?
7. Can you think of any drawbacks associated with airlines developing their own training and assessment programs under AQP?
8. Can access to too much data be a bad thing under the ASIAS program? Please explain.
9. Explain the importance of OSHA and EPA reporting to the aviation industry. List a few examples in which these reports may be necessary.

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FAA on Aviation Environmental Impacts:
http://www.icao.int/Meetings/Green/Documents/day%201pdf/session%203/3-Maurice.pdf

IATA on Improving the Environmental Performance of Aviation:
http://www.iata.org/whatwedo/environment/Pages/index.aspx

OSHA Recording and Reporting of Occupational Injuries and Illness:
https://www.osha.gov/pls/oshaweb/owastand.display_standard_group?p_toc_level=1&p_part_number=1904

Reporting of Environmental Violations:
https://www.epa.gov/enforcement/report-environmental-violations

CHAPTER EIGHT

AIRCRAFT SAFETY SYSTEMS

LEARNING OBJECTIVES

After completing this chapter, you should be able to

- Recognize the importance of jet engine development and advances in solving problems of fuel consumption, noise, reliability, durability, stability, and thrust.
- Describe several breakthroughs in technology associated with the advent of the jet era.
- Explain how improvements in high-lift systems have resulted in safer aircraft.
- List and briefly describe advances that have taken place in five stopping

systems.

- Discuss the importance of stability and control characteristics in relation to safety and give several examples of developments in powered controls and improvements in low-speed stall characteristics.
- Understand how criteria and procedures used in aircraft design over the years have produced long-life, damage-tolerant structures with excellent safety records.
- Explain the concept of fail-safe design.
- List and discuss the parameters that define aircraft aging.
- Describe several approaches and new technologies designed to address the problems of wind shear, volcanic ash, ice, and precipitation.
- Summarize some flight deck technology changes that have made significant contributions to improving safety.
- Explain how computational fluid dynamics (CFD) has enhanced the study of wing design and engine/airframe integration.
- Discuss the importance of the following technologies to aircraft development and safety: wind tunnel, flight simulator, structural tests, flight tests, flight data recorder, and cockpit voice recorder.

INTRODUCTION

The purpose of this chapter is to relate how the wealth of technology and the improvement of design tools have contributed to the excellent safety record of today's jet transport fleet. In addition, a discussion of new technologies that should further improve the safety and efficiency of tomorrow's airplane is included.

Rapid advances in technology have led to the development of extremely complex and highly sophisticated commercial aircraft. A major portion of human tasks that were demanding and performed manually are now automated. Modern autopilot and auto-throttle systems are highly reliable, often more precise than human pilots, and deliver predictable performance in most cases. Modern pilots are increasingly described as system operators who control aircraft mostly through complex interfaces comprised of knobs, dials, and typing on computers and who supervise the work of automated systems, versus directly controlling aircraft through manual inputs on controls. Furthermore, new fly-by-wire aircraft sever the mechanical connection between the pilot and aircraft wing

and tail flight controls. *Fly-by-wire* refers to the electronic linkage from the sidestick (or control yoke) to computers to activate flight controls. This type of system can come in a number of forms. In some aircraft, such as the Airbus A-320 series, it incorporates *protections*, which prevent the pilot from exceeding certain limits.

When such protections were introduced decades ago they created controversy. Some pilots were concerned that automated limits placed on control inputs might limit their ability to operate outside of the normal aerodynamic and performance flight regime during emergency situations. As time passed, many skeptics have come to understand that more danger may lie in overreacting to situations and producing overly aggressive control inputs that result in unrecoverable aircraft attitudes.

For example, a midair collision threat may require rapid pitch and roll inputs where there is no time to consider limits. Aircraft without control input protections may allow a pilot to maneuver the aircraft away from the collision more quickly but risk structural damage by overstressing the aircraft. However, an aircraft with protections against certain inputs may be less effective at changing the trajectory but prevent overstressing the aircraft. Similar situations involve wake turbulence and wind-shear encounters. Over time, pilots are gaining confidence that fly-by-wire systems with built-in protections will not allow limits to be exceeded, which promotes maneuvering to the edge of the *safe* flight limits, probably closer than they would dare with a non-fly-by-wire airplane in the first place.

Much of the technology incorporated into modern commercial aircraft can be attributed to the new and improved design tools that are now available to aeronautical engineers. Wind tunnels, sophisticated simulators, digital computers, and design software have each contributed to the remarkable safety improvements achieved by today’s jet transports. Even the Wright brothers’ achievement was aided (maybe even made possible) by the wind tunnel they built to verify the density of air and the impact on airfoils. Since then commercial aviation has come a long way in how we design aircraft and also individual components, such as aerodynamic surfaces, engines, avionics on the flight deck, and systems to operate hydraulics and other key functions.

Looking back in history to the roots of technology applied to aviation requires acknowledging the role played by World War II, which hastened the development of several different technologies used directly in the development and use of the jet transport. The jet engine, radar, and wing sweep are three of those major technologies. The only airplanes available to the airlines in the late

1940s were propeller-driven, powered by large reciprocating engines. Efforts to increase their size and performance came at the expense of engine reliability. In many accidents, the loss of an engine was a contributing factor.

After the initial development, it was realized that the jet engine offered improved reliability, safety, and performance. The jet engine was at its peak efficiency during high-speed, high-altitude operation. This led to a swept-wing design, which allowed greater aircraft performance. However, early operation at high speed and high altitude, near the airplane's critical Mach number, required careful pilot technique and came at a cost as knowledge of hazards grew. Aircraft were lost during encounters with turbulence as pilots lost control due to aerodynamic effects at high speed, partly due to a lack of protections against losing control of airspeed.

The jet transport era was ushered in during the 1950s with the advent of the British de Havilland Comet, the Soviet Tupolev Tu-104, and the American Boeing 707 and Douglas DC-8. There were many flight safety issues associated with these large swept-wing jet aircraft. This chapter focuses on those technologies that emerged in response to those issues and which proved pivotal to safety as the jet frontier was opened to modern commercial aviation.

JET ENGINE DEVELOPMENT

Credit for the jet engine goes to two individuals who worked independently of each other just prior to and during World War II: Frank Whittle of England and Hans von Ohain of Germany. Through the efforts of General Hap Arnold, the British made Frank Whittle's work available to U.S. engine companies. General Electric (GE) started jet engine development for the Air Force, and Westinghouse started it for the Navy. The effort at GE first produced the axial flow J-47 engine, which was used in quantity in the F-86 and B-47. The work of Pratt & Whitney (P&W) led to the J-57 engine used on the B-52 and Boeing 707 series aircraft.

Very rapid progress was made through the years by the engine manufacturers, solving problems of fuel consumption, noise, reliability, durability, stability, and thrust. The resulting improvements in jet engine performance and reliability rapidly overtook those of the piston engines which were experiencing significant problems with increased size. The reduced complexity and frequency of maintenance of the jet engine decreased the chances of human error. Simplification of controls improved layout and display conditions in the flight deck and also served to reduce the chances for human error.

Jet airplane performance increases were tied in great part to enhancements in the efficiency of jet engines. Improvements in jet engine capability were nothing short of spectacular. Such progress resulted in engine thrust levels required by aircraft manufacturers for satisfying the ever-changing payload-range requirements.

Advances in jet engines over the past half century also reduced noise while simultaneously increasing the range of aircraft, often measured in passenger-miles per pound of fuel burned. Such an evolution is particularly impressive because it has occurred jointly with great enhancements in jet engine reliability and safety. The in-flight engine shutdown rate continued to decrease to the point where a modern airline pilot may never experience an engine failure in his or her entire career. Such a claim would have been inconceivable half a century ago.

Recent Developments in Jet Engine Design

The air transport industry made excellent progress in jet engine developments during the first decade of the 21st century through computer-aided design and testing. Now, next-generation aircraft are making maximum use of the latest composite materials and design processes to reduce weight, improve performance, and lower maintenance costs. Lightweight composites such as graphite, kevlar, and fiberglass are being used throughout the aircraft main structure and also as fan blades in jet engines. Additionally, the fuel performance of the latest aircraft models, such as those manufactured by Airbus and Boeing, is steadily improving, and reduced fuel consumption results in a smaller carbon footprint including less CO_2 emissions on an aggregate level. Likewise, engine noise improvements have been achieved through the slower fan speeds and lower thrust velocity of today’s modern jet engines.

LONG-RANGE COMMERCIAL JET TRANSPORT ERA

A great leap forward for commercial transport airplanes occurred with the development of the Boeing B-47, a military jet bomber that first flew on December 17, 1947, the 44th anniversary of the Wright brothers’ first flight. It all started with the vision of a few designers to adapt this new jet propulsion system to the airplane in such a way as to take full advantage of the jet engine’s performance characteristics. The Boeing Transonic Wind Tunnel (BTWT) was an invaluable engineering tool to establish this new successful configuration. A number of radical airframe differences characterized the experimental B-47 design:

- Highly swept wing (35º)
- High-aspect-ratio plan form (9.43)
- Very wide speed range
- Long-duration, high-altitude operation
- High wing loading (double that of previous designs)
- Thin wing (12% constant-thickness ratio)
- An extremely clean aerodynamic design
- Pod-mounted engines

This design produced a revolutionary performance advantage, but also presented some real safety challenges requiring technological solutions. Some of these challenges were as follows:

- Takeoff and landing lift requirements
- Stopping-distance considerations
- Control system capability over a large speed range and flutter
- Structural integrity for this wing plan form and speed range

These challenges were but a few of the issues that surfaced during the test program following the first B-47 flight on December 17, 1947. An experimental flight test program was undertaken, during which many design decisions were validated and valuable lessons learned. Each of these contributed to today's jet transport safety. More than 2000 B-47s were manufactured, and the airplane remained operational until the late 1960s, again contributing much to today's airplane safety.

Another great leap forward came with the Boeing B-367-80 (Dash 80), which was the prototype for the B-707 airliner. The Dash 80 took full advantage of the B-47 experience. One significant difference from the B-47 was the return to a tricycle gear, which made it possible to tailor its high-lift system for takeoff and landing and to increase the weight on its wheels for improved stopping capability.

HIGH-LIFT SYSTEMS

Development of *high-lift systems*, such as movable aerodynamic surfaces on wings to increase and decrease lift as a function of phase of flight, had to keep pace with the transition from piston engine to jetliner operations. Early jet

bombers used simple trailing-edge flaps and explored, but did not employ, leading-edge flaps. The trailing-edge flaps provided a low-drag solution to the takeoff climbout problem but created another problem for the approach to landing. Since flap drag was low in the approach phase, glide path control was difficult and the power setting of the engines was low, which was a critical shortcoming since it became difficult to quickly increase thrust from the engines to “go-around” power for a missed approach. With the B-47 in the landing configuration, the engines took 13 seconds to reach 60% rpm. This means that when aircraft had to abandon an approach and needed thrust to climb, there was a long delay until the thrust became available. Part of the solution was to incorporate multi-element slotted trailing-edge flaps, which provided the required higher drag and power settings. The remainder of the solution was to reduce the acceleration time for the engines.

The addition of leading-edge flaps resulted in greater safety due to better takeoff and landing performance and greater stall margins. Leading-edge flaps were incorporated on some of the early jet transports primarily because of the different takeoff characteristics of jetliners versus piston-powered airplanes. Prop wash over the wing of propeller aircraft provides a built-in factor of safety at low speeds, enabling the airplane to continue to climb at airspeeds less than the power-off stall speeds. Leading-edge flaps on jets extend the margin of safety to even lower speeds and permit takeoff and climbout margins similar to those in prop airplanes.

The early jetliners operated into and out of a limited number of airports and their high-lift systems were adequate for the range of altitudes and temperatures encountered at these airports. As jet travel became more economical, more number and type of airports were served, and the technology of flap systems changed to accommodate them. In the interest of shorter field-length performance, the Boeing 727 program developed a high-camber airfoil by having a highly deflected slat and a three-element trailing-edge flap system. This system provided the capability to operate at lower approach and landing speeds, giving the 727 the ability to land on shorter runways. Today’s jetliners often incorporate two-position leading-edge slats to provide low-deflection setting for low-drag takeoffs, a higher-deflection position for landing at lower speeds, and better pilot visibility from a lower deck angle.

To enhance safety and improve stall characteristics while maintaining the low-camber leading edge for takeoff, the Boeing 757 added the auto slat to its configuration. This feature provides an extra margin from aerodynamic stalls when the auto slat actuation angle of attack is reached. This feature also provides additional maneuvering margin in the case of a wind-shear encounter.

Stopping Systems

A number of improvements in aircraft stopping systems have taken place over the years, greatly enhancing safety. They include antiskid, fuse plugs, autobrakes, speed brakes, and thrust reversers.

Antiskid Braking. The higher takeoff and landing speeds for jetliner operations compared with prop airliners created the need for more efficient stopping devices. An antiskid braking system was recognized as a necessity early in the jet age. Most of the time pilots do not need the antiskid feature of brakes, especially if the runway is dry and long, since the brakes are not applied hard enough to skid the tires. However, when the runway is slippery and short, the ability of the *antiskid system* to maximize braking effectiveness becomes very important.

Early antiskid systems were developed and tested successfully on the dual-wheel main landing gear assemblies of large propeller-driven aircraft. However, the design of antiskid systems soon became a new technological challenge because of the incorporation of multiple-wheel main landing gears on the first jetliners. The early antiskid systems for the four-wheel truck main gears controlled tandem pairs of wheels. Later the technology to control each wheel independently was incorporated to maximize the effectiveness of the antiskid system. Digital antiskid systems incorporating microprocessors enhance the reliability and effectiveness of today's modern antiskid braking systems.

Fuse Plugs. Air pressure buildup in tires after braking during early high-speed rejected-takeoff tests often caused the tires to explode, sending chunks of rubber flying into the airframe. Incorporation of low-melting-point fuse plugs in the wheels allowed the tires to safely deflate before severely heating and exploding.

Autobrakes. The incorporation of *an automatic braking system* is a relatively recent enhancement to safety. This system enables automatic brake application on landing or during a rejected takeoff (RTO). The landing autobrake system controls brake pressure to maintain aircraft deceleration at one of several pilot-selected values, provided that sufficient runway friction is available to maintain this level. The RTO autobrake system applies full braking upon closing throttles above a fixed speed (e.g., 85 knots). Using autobrakes frees the pilot to concentrate on other activities, such as applying reverse thrust and directional control of the airplane to achieve a smooth, safe stop on the runway.

SPEED BRAKES. While main wheel brakes remain the primary method of stopping aircraft on the runway, technological development of ancillary stopping devices has kept pace with development of wheel braking systems. These devices are aerodynamic in nature but serve to enhance the efficiency of wheel brakes. The need to apply a download on the wheels was recognized as a requirement to enhance the effectiveness of wheel brakes. The use of *wing spoilers (speed brakes)* to decrease lift, and therefore increase download on the main wheels to enhance braking effectiveness, was incorporated on the early jets. The percentage of wingspan covered by these devices has increased on later models, increasing their effectiveness. Implementation of automatically deployed spoilers on later models has enhanced stopping capability significantly. Sequencing of the spanwise spoilers after touchdown eliminates pitchup, which can occur when all the spoilers are deployed simultaneously at close to airborne speeds.

THRUST REVERSERS. Commercial jet transport operation into regional airports would not have been possible without *thrust reversers*. Although FAA regulations did not require thrust reversers, they were a must for most airline customers. It was very desirable that jetliners be able to land on slippery runways within the FAR-required field length. Early experience revealed that some types of thrust reversers lost their effectiveness at high landing speeds, which required the airframe manufacturers to conduct tests to verify early reverser concepts.

Designs of the Boeing 737-100 and 737-200 presented a difficult challenge in integrating the thrust reversers because the engines were mounted very close to the lower surface of the wing and very close to the ground. The initial design decision was an economic one: use the entire power package and nacelle from the Boeing 727. However, the resulting reverser configuration partially trapped the reverser efflux between the trailing-edge flaps and the leading-edge devices, creating a “bubble” of air on which the airplane floated in ground effect, greatly reducing stopping effectiveness. A complete redesign of the reverser, including a lengthening of the nacelle to accommodate a target reverser aft of the flaps, resulted in a tremendous improvement in stopping capability. In fact, the Boeing 737-200 has such an effective reverser that the airplane can stop within its required distance on a wet runway using only thrust reversers.

LOW-SPEED STALL CHARACTERISTICS. Design of the high-lift systems was a challenge in that these systems had to provide commercial jets with safe takeoff and landing margins in all places and conditions. The system also has to exhibit

satisfactory flying qualities in the extremely unlikely event of an aerodynamic stall.

Early swept-wing designs exhibited poor stall characteristics because the wing tip would stall first. The remaining inboard wing lift, being ahead of the center of gravity, would give the aircraft an undesirable pitchup tendency. Wing technology involving the selection of airfoils, wing twist, and tailoring of the leading-edge and trailing-edge flaps was initially advanced through the use of wind tunnels, then flight testing. Later, the understanding of this problem was greatly advanced through the use of computational fluid dynamics (CFD).

Two technologies, the *stick-shaker* and *auto slat gapper*, have been effective in avoiding aerodynamic stalls during both takeoff and landing. The best design philosophy is first to work on avoiding the stall. Some airfoil-wing combinations provide adequate stall warning to the pilot by virtue of disrupted airflow shaking the aircraft so that pilots notice that a stall is imminent, an effect called wing buffeting that occurs as the stall angle of attack is approached. As high-performance wings were developed, this buffet margin was found inadequate, and a "stick-shaker" was provided. The technology of this system involved finding the best sensor and location for early notification. The auto slat was implemented when it was found that the characteristics of a sealed slat, which had improved takeoff performance, had poor flying qualities at stall. The solution was to open the slat gap automatically as wing stall was approached.

Stall safety was greatly improved by use of the simulator. Early in demonstrating airplane stall and recovery techniques, it was found that the situation was too unforgiving to a pilot applying improper technique. Today, stall avoidance and recovery training are carried out safely in the simulator. Stall characteristics are thoroughly investigated during flight tests involving, in many cases, more than 700 stalls. The designer is anxious to get as low a stall speed as possible for overall safety.

STRUCTURAL INTEGRITY

The importance of structural integrity to commercial aircraft safety is obvious. When cracks are created in structures they can grow to a certain size where they propagate catastrophically and can ultimately lead to structural failure. Advances in the field of fracture-mechanics, such as the use of materials inherently resistant to crack growth, not only prevents dramatic events such as wings separating from aircraft in flight, but also extends the operational life of aircraft well beyond what many could have imagined. The life of commercial aircraft is measured in decades and, in some instances, can even span half a century.

A real challenge in military aviation is the flight loads imposed on aircraft performing low-level missions, which commonly occur at or below 1,000 feet above the ground, where turbulence from the rising heated air close to the ground can impose significant structural stress on an aircraft. From a structural perspective, 1 hour of low-level flight was equivalent to 80 hours at cruise. These lessons learned were shared with all, and manufacturers of commercial aircraft have been benefiting from these improvements in safety ever since.

Several material fracture-mechanics properties came to light. For example, laboratory data compared the tensile strength of three different aluminum alloys as affected by the length of a crack. In the past, it was general practice to design engineering structures such as aircraft, bridges, buildings, and pipelines to a required amount of strength for an undamaged structure, plus a certain margin of safety. This factor of safety was intended to provide for degradation by corrosion, fatigue, damage, *etc.* It is clear today that aircraft engineering structures should be designed to maintain adequate strength not only when new and undamaged, but also after they have sustained fatigue, corrosion, and damage from routine use to a level that can be perceived during a thorough inspection.

A lot of credit for advancements in this area is attributed to the electron microscope. By conducting electron microscope examinations on failure surfaces of failed structures, it became clear that each time the structure was loaded, there would be crack growth. The initiation and growth of cracks could be identified with their prior load. It was also clear that the fatigue and corrosion cracks of most aircraft materials start at the exposed surface of the material, permitting inspection for fatigue and corrosion cracks for most installations. The attention of aircraft designers became focused on the rate at which cracks grow, the strength of cracked structures, and the variation of these factors for different materials. Considerable attention was also given to understanding the loading cycles commercial aircraft would actually encounter in service.

STRUCTURAL SAFETY. Criteria and procedures used in commercial airplane design over the last three to four decades have produced long-lived, damage-tolerant structures with excellent safety records. This has been achieved through diligent attention to detail design, manufacturing, maintenance, and inspection procedures. Structural safety has been an evolutionary accomplishment, with attention to detail being the key to this achievement. These design concepts, supported by scientific testing, have worked well due to the system that is used to ensure that the fleets of commercial jet transports are kept flying safely throughout their service lives. This system has three major participants

(stakeholders):

- The manufacturers that design, build, and support those aircraft in service
- The airlines that operate, inspect, and maintain the aircraft
- The governmental airworthiness authorities who establish rules and regulations, approve the design, and promote airline maintenance performance

Aircraft structural safety depends on the diligent performance of all participants in this system. The responsibility for safety cannot be delegated to any single stakeholder.

All jet transports are designed to be damage-tolerant, a concept that has evolved from the earlier fail-safe principle. On the whole, service experience with fail-safe designs has worked very well with thousands of cases where fatigue and other types of damage have been detected and repaired. The question being debated among experts in the industry is whether the fail-safe design practices used in the 1950s and 1960s are adequate as these airplanes approach or exceed their original useful life objectives. Note that there is almost no limit to the service life of damage-tolerant-designed aircraft structures, provided that the necessary inspections are carried out along with timely repair and replacement of damaged equipment.

AGING AIRCRAFT. One of the major problems facing the FAA and air carriers today is aging aircraft. By definition, aging aircraft are aircraft that are being operated near or beyond their originally projected design goals of calendar years, flight cycles, or flight hours. Nothing in the FARs pertains directly to the useful life of an airplane as measured in calendar years, but it was customary for designers to assume approximately 20 years as the calendar life of an aircraft. For the first generation of jet transports, some designers believed that the aircraft would be technically obsolete within 20 years. Using this measure, a number of the earlier models of the DC-9s, Boeing 737s, Boeing 727s, Boeing 747s, and DC-10s still flying today would fall into this category; not to mention the DC-3 aircraft that are an astonishing 80 years old and still in commercial service.

The two important measures of age are the number of flight cycles and the number of flight hours accrued in service. Both must be carefully considered.

Recent regulatory changes by the FAA have clarified aging aircraft monitoring requirements. Commercial aircraft were designed and certificated in the United States after World War II in the belief that with proper inspection,

maintenance, and repair, the life of the airframe could be unlimited. The foundation for this premise was the adoption of the principle of *fail-safe design* by the FAA and the industry in the early 1950s. This rule required that a specified level of residual strength be maintained after *complete failure* or *obvious partial failure* of a *single principal structural element*. The early U.S. jet and propjet fleets were designed, tested, and FAA certified to this rule without a specified life limit. The service experience acquired by this fleet by the middle to late 1970s had generally shown a satisfactory level of structural safety and provided many documented instances of the validity of the fail-safe concept.

However, the unusual nature of the circumstances of Aloha Airlines Flight 243 greatly accelerated the research about aging aircraft. On April 28, 1988, a Boeing 737-200 suffered an explosive decompression in flight which required an emergency landing on the Hawaiian island of Maui. The NTSB investigation report concluded that the accident was caused by metal fatigue. The age of the aircraft became a key issue (it was 19 years old), and the 737 had sustained a remarkable number of takeoff-landing cycles, 89,090, the second most such cycles for a plane in the world at that time. The Aloha Airlines accident of 1988 focused public and congressional attention on *aging aircraft*. This accident and other structural failures stimulated a reexamination of the current approaches to the structural integrity of aging aircraft.

Fatigue-initiated damage is the primary concern about aging aircraft. When aircraft are properly inspected and maintained, corrosion and accidental damage should be managed and controlled long before the design life is reached. On the other hand, the problem of fatigue-related damage increases with time or, more properly, with prolonged use as measured by flight hours or flight cycles or both. Fatigue damage to the fuselage is caused primarily by the repeated application of the pressure cycle that occurs during every flight. Fatigue damage to the wings is caused by the ground-air-ground cycle that occurs during every flight, pilot-induced maneuvers, and turbulence in the air. Thus, the goal of measuring aircraft structural safety by flight hours is more important for the wings than it is for the fuselage.

Fatigue-related damage occurs randomly. The chance of damage due to fatigue for any given point in a structure will increase with time. Because detecting the damage is also probabilistic, structures must be designed so that they can withstand harm, which is a concept called *damage tolerance*. Such tolerance is key to preserving airworthiness. A large transport airplane is a complex structure in which a large number of points are susceptible to fatigue cracking that could propagate to the point at which the residual strength would

be less than the damage tolerance requirement. The number of points in the structure at which cracks will initiate increases with the age of the structure. As the number of initiation sites increases, the probability increases that inspectors will not detect at least one crack before the strength degrades to the structural limit. In other words, during the aircraft life cycle, the risk of not having limit-load capability at some point in the structure may be too great for the airframe to be considered airworthy. Thus, even an airframe designed to be damage tolerant may reach a time in its life when additional inspections, maintenance, and repair will be required to maintain airworthiness. A common fatigue scenario for the fuselage includes the following:

- Cracks initiate at the edges of the fastener holes in the center of the panels along a splice.
- With repeated flight cycles, these small cracks link to form a patch spanning several holes.
- The patch becomes sufficiently long that it is detected during scheduled checks before rapid growth occurs.

Rapid growth, if it occurs, will be arrested by crack turning at the tear straps or the frame or both, resulting in a progressive, safe depressurization that permits the pilot to safely land the airplane. Although this scenario has actually occurred, it is not the only possible scenario. At least two other scenarios can be envisioned in which cracking may not be arrested by the tear straps (e.g., if the fastener holes in the tear straps already contain small cracks or if there is widespread cracking in several adjacent bays).

In these circumstances, the crack may continue to propagate rapidly along the splice and lead to uncontrolled depressurization, in which case neither the tear straps nor the frame is fulfilling the original fail-safe function. This, in fact, is what occurred during the Aloha Airlines event—the uncontrolled crack propagation resulted in the loss of a large portion of the fuselage. The structural condition described, wherein widespread cracking in tear straps and adjacent bays occurs, is called *multiple-site damage (MSD)*. Clearly, MSD is more likely to exist in heavily used aircraft. A key factor in maintaining the safety of aging aircraft is the determination of age in flight cycles, flight hours, or both, of the onset of MSD.

It is assumed in analyses of this phenomenon that the airframe was designed and manufactured as intended, such that aging is related to the *wear-out* phase of the well-known *bathtub curve*. Because neither design nor manufacturing control

is perfect, cracks occur in airframes long before the design goal life is reached. This is not an aging phenomenon but should be considered as the population of locations in which the design or construction was deficient (i.e., local "hot spots"). Some cracks are revealed by the airplane fatigue tests and others during the early service experience with the aircraft. As cracks are detected and corrective action is taken, the rate of new hot-spot cracking decreases with time; the net result is that the total population of crack locations at any given time would be small. Experience has shown that the risk of undetected cracks during this phase of the operational life can be controlled to a safe level by appropriate inspection and maintenance programs.

Fortunately, the action taken by the FAA in the wake of the Aloha Airlines accident has been noteworthy. In 1991, the U.S. Congress passed the Aging Aircraft Safety Act which required air carriers to demonstrate that maintenance of an airplane's age sensitive parts has been "adequate and timely enough to ensure the highest degree of safety." This legislation was codified by the FAA as the *Aging Airplane Safety Rule (AASR)* and requires airlines to ensure that repairs or modifications made to their airplanes are damage tolerant. On January 25, 2005, the FAA issued its final AASR regulation which requires repetitive inspections and record reviews every 7 years for all transport airplanes greater than 14 years old. In November 2007, the FAA issued Advisory Circular 120-93 to provide detailed guidance for "Damage Tolerance Inspections for Repairs and Alterations." Three years later, in November 2010, the FAA issued its final rule which is considered a comprehensive solution to the problem of widespread fatigue on aging aircraft. This new rule seeks to prevent *widespread fatigue damage (WFD)* by requiring aircraft manufacturers to establish a specific number of flight cycles or hours an aircraft can operate and be free from WFD without additional inspections for fatigue. At least 4,000 U.S. registered aircraft are affected by this new rule, and if adopted worldwide, the number of affected airplanes could more than double.

CABIN SAFETY

Where is the safest place to sit in an airplane? The many people who posed this question in 1985 realized that surviving an airplane crash is often possible. But few of them also appreciated that survival and cabin safety depend a great deal more on other factors than seating position. Better emergency procedures and equipment, different cabin materials, and stronger seats can contribute to higher survival rates.

In 1985, the NTSB addressed the issue of cabin safety on several fronts. It

issued a study on emergency equipment and procedures relating to in-water air carrier crashes. The study found that equipment and procedures were either inadequate or designed for *ditching* (emergency landing on water where there is time to prepare and that involve relatively little aircraft damage) rather than for the more common short (or no warning) in-water crashes. The NTSB recommended improvements in life preservers, passenger briefings, emergency-evacuation slides, flotation devices for infants, and crew post-crash survival training.

Later in the year, the NTSB completed a study on airline passenger safety briefings. The NTSB concluded that in the past, “The survival of passengers has been jeopardized” because they did not know enough about cabin safety and evacuation. The study also found wide variances, and sometimes inaccuracies, in oral briefings and in information on seatback-stored safety cards.

Effective evacuation of an aircraft also depends on the quick action of flight attendants. In October 1985, the FAA issued a notice of proposed rulemaking to require protective breathing equipment for flight crews and cabin attendants. The NTSB had recommended making this equipment available following its investigation of the fatal fire on the Air Canada DC-9 at Cincinnati International Airport in June 1983. The recommendation repeated one made a decade earlier after the NTSB participated in the investigation of a foreign accident involving a cabin fire. The NTSB believed that without protective breathing equipment, flight attendants could easily be incapacitated by fire and smoke, could not make effective use of fire extinguishers, and could be of no use during an evacuation. In 1985, the NTSB also supported a petition for rulemaking to set flight attendant flight-duty time limits.

In view of public attention to the issue of cabin safety, the FAA has taken a number of regulatory actions to increase the likelihood of passenger survivability in aviation accidents. Among these improvements are the following:

- Fire-blocking seat cushions to prevent fire or to mitigate its effects. FAA Advisory Circular 120-80, dated January 8, 20041/8/2004, provides detailed guidance on how to deal with in-flight fires, emphasizing the importance of crewmembers taking immediate and aggressive action.
- Emergency floor lighting to improve the chances and speed of evacuation by 20% under conditions where there is significant smoke in the cabin. Improved passenger safety briefings and cabin safety data cards have also made a positive impact.
- Stronger seats that must be able to withstand 16 times the force of gravity (16

g) are required for Part 121 aircraft that were built after October 27, 2009. Using a test dummy, these seats must undergo dynamic testing and evaluation to ensure they are effective in the demanding aviation crash environment.

SAFETY DESIGN FOR ATMOSPHERIC CONDITIONS

Long-duration, high-altitude, and high-speed flight can be significantly impacted by many diverse atmospheric phenomena. Four of the more important areas of concern include the following:

- Turbulence
- Wind shear
- Volcanic ash
- Ice and precipitation

The first line of defense should always be to detect and avoid these hazards. When this strategy is impractical, the solution must address safe operations and maneuvers in the event of an adverse encounter. Great progress has been made in both areas.

TURBULENCE

Earlier it was mentioned that very low altitude flight imposes particular stress on military aircraft operating in that regime. Operating at higher altitudes, as is common with commercial aircraft, also produces encounters with turbulence that create structural stress on aircraft. To measure such an impact, aircraft manufacturers developed a velocity-load factor altitude recorder. Results of the measurements collected by the recorders showed the need for further research, with specific interest being the area of *High Altitude Clear Air Turbulence (HICAT)*. Data collected in this program markedly changed the design criteria of commercial and military jet airplanes.

Early in the jet era, there were a number of what are referred to as “jet upsets” from severe air turbulence encounters. Study of these encounters led to a better understanding of how to safely fly jet aircraft in such an encounter. Results indicated that it was important not to change aircraft trim, but to disengage the early autopilot’s autotrim feature and airspeed/Mach hold only if necessary, and to fly attitude and let the airspeed and altitude vary somewhat.

Between 1983 and 1997, the NTSB investigated 99 turbulence accidents and incidents that had resulted in two fatalities and 117 serious injuries. Most of

incidents that had resulted in two fatalities and 117 serious injuries. Most of these injuries—many of which involved fractures of the spine, skull, and extremities—were completely preventable if the occupants had been restrained by seatbelts.

Since 1972, the NTSB has made several safety recommendations to the FAA and the National Weather Service (NWS) and has been involved in numerous investigations dealing with the hazards of turbulence. For example, in March 1993, an engine of a Boeing 747 cargo flight separated from the airplane in severe turbulence while departing from Anchorage, Alaska. As a result of this investigation, the Board recommended that the NWS develop turbulence forecasts in greater detail using data from the Doppler weather radars. The NWS has implemented this recommendation.

The Board also investigated another severe turbulence encounter involving a United Airlines Boeing 747 that occurred in the western Pacific on December 27, 1997. This encounter resulted in one fatality and many injuries to passengers and flight attendants. The Board's investigation focused on turbulence forecasting, flight crew training, dissemination of information on turbulence, and crew procedures in areas where turbulence is forecast.

The NWS Aviation Weather Center and the NOAA Earth System Research Laboratory are also making progress in improving clear air turbulence and mountain wave forecast products. Furthermore, the FAA Aviation Weather Research program has a multidisciplinary team addressing the turbulence problem, and researchers from the National Center for Atmospheric Research (NCAR) are working on new algorithms for using data from the NWS Doppler weather radars to detect turbulence. The NCAR researchers are also developing software that may be able to turn an airborne commercial aircraft into a real-time turbulence-sensing platform. The software will use onboard sensors and computers to measure and analyze turbulence as the aircraft flies through it. The data will be transmitted to the NWS, where they will be used to create accurate, real-time turbulence maps for use by pilots, air traffic controllers, and dispatchers.

WIND SHEAR

With the increased frequency of flights, the number of wind shear–related takeoff and landing accidents has also increased. The first part of investigations into *wind shear* involves isolating the wind profile associated with the event. Improved onboard data recorders on test airplanes showed the profiles were more severe than previously known. Additionally, the downburst phenomenon

associated with certain weather conditions was discovered. A three-pronged approach was initiated. The first prong involved training crews on avoidance of the phenomena, the second related to better detecting the conditions that can produce wind shear and alerting the crew, and the third prong dealt with getting maximum performance from the airplane if the crew inadvertently encountered wind shear.

Good-fidelity simulators were used for this analysis. In evaluating ways in which pilots can achieve the greatest performance from the airplane, it was possible to use the latest technologies that were being incorporated in advanced flight decks. A very successful task force composed of individuals from the FAA, airplane manufacturers, and airlines made a great contribution to safety by producing a wind-shear training aid for flight crew avoidance and procedures for getting maximum performance in the presence of wind shear. Additionally, algorithms were developed and displays were modified to provide guidance and situational awareness, which also enhanced flight crew performance.

Another winds-aloft hazard is mountain waves, especially in high-risk areas such as Alaska and over the Rocky Mountains of the United States. The loss of a Boeing 707 near Mount Fuji in Japan was the result of such an occurrence. We still have a lot to learn about wind in the vicinity of mountains, and the supercomputer's contribution to modeling this phenomenon gives hope for further improving the safe operation of aircraft in this environment. Also needed is further research on sensors capable of detecting these unusually adverse winds.

VOLCANIC ASH

Volcanic activity has occurred throughout the world since the earliest of times. The first recorded impact on aviation was on March 22, 1944, when Mount Vesuvius did more damage to an airfield than enemy activity during that period of World War II. It was another 36 years before the next direct impact, in 1980, when a civil Lockheed C-130 Hercules inadvertently penetrated a dense ash cloud from Mount St. Helens in western Washington following its second major eruption. The aircraft lost power on two of its four engines but the crew was able to return and land safely at McChord Air Force Base.

In 1982 a famous incident occurred when a British Airways Boeing 747 operating between London and Auckland inadvertently flew through a volcanic ash cloud of Mount Galunggung in Java, Indonesia, resulting in all four engines simultaneously flaming out. Fortunately, the crew managed to keep their composure and glide the large jet down to lower altitudes where a relight of the

engines was possible. Since then, there have been several major eruptions worldwide, and they will undoubtedly continue in the future.

The most serious recent volcanic ash eruption was reported on April 14, 2010 when ICAO's authority in London issued an alert that a strong ash plume was moving from the eruption of the Eyjafjallajökull volcano in Iceland toward northwestern Europe. The difficulty in pronouncing the name of the volcano by non-Icelandic speakers led to the somewhat curious appellation of "E+15" by some members of the airline industry when referring to the volcano. The International Air Transport Association (IATA) reported that the eruption resulted in the sudden closure of large areas of European airspace, around 100,000 flights were cancelled, 10 million passengers were affected, and total economic damage reached almost 5 billion dollars. The danger of engine flameout and severe damage to aircraft was significant for 2 weeks. The situation was so grave that the day following the start of the eruption became known as "Ash Thursday" by the airline industry. Over 17,000 flights were cancelled on some days, incurring losses of some $200 million per day. Figure 8-1 shows the appearance of E+15 during the eruption.

FIGURE 8-1 E+15 erupting in Iceland on April 17, 2010. (*Source: Wikimedia Commons*)

The risk to commercial aviation safety posed by volcanic ash cannot be overstated. ICAO has set a maximum limit of 4 mg of silicate ash per cubic meter in the clouds associated with eruptions of volcanoes such as E+15 as the safe limit of ash concentration for ingestion by jet engines. When ash is ingested into a jet engine, it erodes metal, melts, forms a glassy coating on turbine blades, and can clog both fuel and cooling systems. Because the nature of ash clouds makes it difficult to measure them with accuracy, and because pilots do not have access to detection systems, nor ways of differentiating ash clouds from routine clouds with accuracy, it is prudent to avoid such cloud areas by a significant safety distance. Figure 8-2 shows the stunning range of the E+15 ash cloud on one of its worst days during the eruption, and therefore, makes clear the enormous disruption it created to air travel over northern Europe.

FIGURE 8-2 E+15’s ash cloud on April 10, 2010. (*Source: U.K. Aviation Meteorology Office*)

In the wake of the Icelandic volcanic crisis, ICAO is currently working with European aviation authorities to improve the forecasting of volcanic ash trajectory and dispersion. A mobile radar unit will soon be deployed in Iceland to improve the accuracy and speed of information on the height of any future ash cloud. An accurate assessment of the height of the initial ash plume is critical for predicting its subsequent movement and dispersion. A coordinated European

approach to this problem is in process under the “Single European Sky” initiative. It is highly desirable to base future decisions about airspace use on scientific measurements since significant angst resulted when airspace was closed during Eyjafjallajökull’s eruption based on theoretical models and inaccurate observations.

Further research and planning is urgently required. Another volcano in Iceland named Katla could potentially pump 10 times more ash into Europe’s skies than E+15. The volcano has a history of erupting every 40 to 80 years but has not done so since 1918. It is overdue! The only positive aspect of the situation is that this Icelandic volcano, at least, has a more pronounceable name than Eyjafjallajökull.

ICE AND PRECIPITATION

Ice and precipitation impact airplane operation in two areas. One is the effect they have on the airframe and engine, and the second is the effect on tire-ground contact. Unlike the previous atmospheric topics, these elements are daily occurrences, with severity and likelihood of encounter depending on the season and location. Safe operations depend on a coordinated team effort by airline maintenance crews, flight crews, and airport authorities, as well as ground and air traffic control (ATC). The technologies that help are many and depend on specific icing or precipitation conditions. Again, teamwork and procedures play an important role. Flight simulator training continues to be an effective tool in developing correct takeoff and landing procedures for ice-contaminated runways to keep safe operation possible.

Developing all these procedures involves extensive wind-tunnel, environmental laboratory, and flight tests to fully understand the problems and show performance of the airplane under icing conditions. The contribution to safety in some of these cases is focused on understanding the limitations of the airplane under such adverse weather conditions. Only then is safety improved when those responsible for each aspect of the operation implement the procedures that come from these tests.

In-flight icing is one of the FAA’s top weather research priorities. Improved operationally available, high-resolution, accurate forecasts of atmospheric icing conditions are needed. Several safety recommendations dealing with in-flight icing were issued as the result of the NTSB’s investigation of the ATR-72 accident that occurred at Roselawn, Indiana on October 31, 1994. These recommendations and the findings from the investigation provided the major impetus to the icing research efforts of the FAA.

Then again on January 9, 1997, Comair Flight 3272, an Embraer 120, crashed near Monroe, Michigan, destroying the airplane and killing all 29 people onboard. There were reports of moderate icing in the area at the time of the accident. In May of the same year, the NTSB issued four urgent safety recommendations to the FAA regarding icing. Almost concurrently, the FAA issued a notice of proposed rulemaking to modify operating procedures in icing conditions. Comair modified its operating procedures based on the FAA's proposed rule, and the FAA issued a final rule. The Board also worked with the National Center for Atmospheric Research and the NASA Lewis Research Center regarding weather issues. In January 1998, Board personnel traveled to Brazil, where the airplane was manufactured, to review all pertinent test data on icing and to perform studies in the engineering simulator.

Issues examined regarding this accident included flight crew training, operations in icing conditions, and aircraft performance. This accident resulted in several significant research activities, including the quantification of the loss of performance due to small amounts of surface roughness on a wing's leading edge and the performance penalties associated with deicing boots.

In recent years, the NTSB and FAA have become more definitive in the area of ice detection and prevention. On August 3, 2009, the FAA published a final rule that became effective September 2, 2009. Although the new rule does not address existing airplane designs, the FAA is considering similar rulemaking that would apply to those designs. Under the revised certification standards, new transport aircraft designs must incorporate one of three methods to detect icing and to activate the airframe ice protection system:

- An ice detection system that automatically activates or alerts pilots to turn on the ice protection system.
- A definition of visual signs of ice buildup on a specified surface (e.g., wings) combined with an advisory system to alert the pilots to activate the ice protection system.
- The identification of temperature and moisture conditions conducive to airframe icing that would alert pilots to activate the ice protection system.

The new FAA standards further require that, after initial activation, the ice protection system must operate continuously, automatically turn on and off, or alert the pilots when the system should be cycled.

FLIGHT DECK HUMAN–MACHINE INTERFACE

The technology topics discussed to this point have dealt primarily with the design aspects of the airplane as a machine and its capability to operate safely in the atmospheric environment. This section takes a look at the technology that involves the human–machine interface. It involves the flight crew and one or more other parties: maintenance, ground operations, weather forecasters, air and ground traffic control, and others. In commercial aviation safety matters, it all comes together on the flight deck.

The human–machine interface often becomes a determining factor in the event of an emergency, where correct, timely decisions and proper execution make the difference between life and death. As discussed earlier in this text, human factors is the science that covers the human–machine interface in an attempt to maximize the potential for safe, efficient operation while eliminating hazardous conditions resulting from human error.

Technology on flight decks has improved continuously since the early days of aviation. Notable advancements are radio communication, radio and inertial navigation, and approach systems. The jet engine greatly simplified cockpit controls and displays. The following are some of the flight deck technology changes that have made a significant contribution to improving safety:

- Crew alerting and monitoring systems
- Simple system designs
- Redundant systems
- Automated systems (when essential)
- Moving Map displays
- *Engine-indicating and crew-alerting system (EICAS)*
- Glass cockpit displays with color enhancement
- *Ground-proximity warning system (GPWS)*
- *Traffic Collision Avoidance System (TCAS)*
- *Aircraft Communications Addressing and Reporting System (ACARS)*
- Flight management system (FMS)
- *Head-up display (HUD)*

Early Flight Deck Development

The Boeing 707, Boeing 727, DC-8, early Boeing 747, DC-10, and L-1011 flight decks used a standard three crew arrangement consisting of a captain, first

officer, and flight engineer. Much like the previous aircraft, the airplane systems were designed for the flight engineer to be the systems operator. Large instrument panels were mounted behind and to the right of the two pilots. The flight engineer was also expected to monitor and operate the vital hydraulic, electrical, fuel, air conditioning, and pressurization systems with minimal supervision. The design of the short-range Boeing 737 was changed radically to provide a flight deck that only needed a two-person flight crew.

To accomplish this crew reduction, the airplane systems were first simplified. The fuel system, for instance, now only has three tanks: a right-wing tank for the right engine, a left-wing tank for the left engine, and a center tank to be used by both engines. The fuel boost pump capacity, line sizes, and fuel head were designed to permit fuel from the center tank to be used first, followed by wing fuel, without any crew action following the prestart checklist. When the center fuel is depleted, amber lights annunciate to the crew to inform them that the center tank pumps can be turned off. A cross-feed system is provided for non-normal operations. This simplified system has other benefits besides crew workload reduction.

Multiple sources of power or supply are provided on all systems to ensure adequate system function when one or more elements has failed. Multiple hydraulic pumps are also provided, driven in different ways to provide a completely redundant system.

The control system on the Boeing 727 uses cables from the control column to hydraulic actuators for normal operations. However, if the two hydraulic systems fail, a system of cables to the flight controls provides a *manual reversion* method of controlling the aircraft. The Boeing 757 is a newer-generation aircraft and takes a different approach to redundancy. It has three hydraulic systems, an engine pump, an electrical pump, and a ram air turbine as a backup system. This replaced the direct cable-to-control connection. The Boeing 747 is similar, with four hydraulic systems and no direct cable-to-control connection. At least one hydraulic system and pump must be operating to move the flight controls. The Airbus A-320 also requires at least one hydraulic system and pump to move flight controls. The A-320's redundancies include three hydraulic systems, two engine-driven pumps, two electric pumps, a power transfer unit (uses one hydraulic system to pressurize another), and a ram air turbine in case alternating current electric power is lost.

Automatic operation of a system was also provided for selected equipment failure cases to avoid the necessity of crew intervention at a critical time in flight. The Boeing 737 electrical system load-shedding feature is an example. In the event of a single generator failure on the two-generator nonparalleled

electrical system, the remaining generator picks up the essential load, and nonessential loads are shed. The galley power and other similar loads are shed so that the remaining generator can provide all essential electrical loads without the need for crew attention or intervention. Later, when the crew has time to restore a second generator, the shed loads can be recalled. This same design philosophy has prevailed through the other two-crew designs on the Boeing 757, Boeing 767, and Boeing 747-400 aircraft.

Flight Deck: Boeing 757/767 and Boeing 747-400

Flight deck noise levels are low enough today to allow a true "headsets off" environment for the pilots. While the forward windshields are flat for best optical characteristics, the side windows are curved to prevent turbulent airflow and reduce the associated aerodynamic noise. Wind-tunnel studies showed that the aerodynamic vortex created by the sharp angular change between the flat forward and flat number-two windows contributed to cockpit noise levels at cruise airspeeds. This source of noise has been eliminated in the Boeing 757/767 flight deck. The air-conditioning system is designed to further reduce flight deck noise by means of ducting improvements and lower airflow velocities.

Vision characteristics are excellent inside and outside the Boeing 757/767. Vision through the windshields exceeds Society of Automotive Engineers (SAE) recommendations, allowing pilots superior collision avoidance capabilities when visually clearing for traffic. Also, improved downward visibility and maintaining a low deck-approach angle combine to give an extra margin of safety when landing in adverse weather conditions.

In this "quiet and dark" flight deck, few green or blue lights indicating normal system operation are used. Lighted pushbutton switches that combine the amber malfunction light with the shutoff switch are used to reduce the possibility of incorrect crew action.

The integrated display system (IDS) in the Boeing 747-400 consists of six 8-inch square screens. Although all are identical, each performs a different function depending on its location:

- *Primary flight display (PFD)*
- Navigation display (ND)
- Engine indication and crew-alerting system (EICAS)

The two outboard cathode ray tubes directly in front of the pilots function as the captain's and first officer's primary flight displays (PFDs). Each pilot can

the captain's and first officer's primary flight displays (PFDs). Each pilot can use the PFD as the single source for all the primary flight instruments found on a traditional instrument panel. The tape formats used for altitude, airspeed, and heading/track indications were chosen for two reasons: (1) they permit sufficient display resolution without disrupting the “basic T” instrument configuration; (2) the tape formats more readily accommodate related supplemental information. This information, such as speed bugs and a trend vector, increases pilot situational awareness.

AUTOMATION

Automation has touched so many facets of today’s society. The impacts of automated systems are very visible in the aviation sector. For example, on the modern flight deck, automation provides pilots with information such as how much fuel will be available at the destination and where the top of a climb is in order to optimize the flight path and takes care of many functions that were previously accomplished by the pilot, such as calculation of takeoff and approach speeds. Although automation has solved many problems and reduced some types of workload, it is also causing new and different types of aviation safety challenges.

Automation is beneficial because it can greatly aid human decision making. Two main points have led to the adoption of automation on board: the desire to reduce human error and the desire to enhance efficiency for better economic performance. Although humans are prone to making mistakes, with the help of computer-based algorithmic processes, the pros and cons of each situation can be based on facts and logic instead of other human intuition and deduction. Additionally, as the airline industry continues to grow at a fast pace, automation helps train pilots and allows them to operate aircraft at maximum economic efficiency, such as using autoflight systems that result in fuel savings.

In the right setting, automation can increase capacity and productivity, reduce manual workload, and provide precise handing of routine operations. Some items that help achieve this are *multifunction displays (MFDs)*, autopilots, auto-throttles, digital flight guidance panels, and FMS. MFDs provide numerous types of information to a pilot, depicting items such as location, system status, and even checklist steps. Having such information immediately available can reduce workload, which leaves more time for thinking and making decisions. Automatic flight systems, such as auto-throttles and the autopilot, can significantly reduce pilot workload and thus prevent pilot fatigue. FMSs are specialized computers that automate several in-flight tasks, such as managing the

flight plan and estimating fuel burn and times at different navigation waypoints. These automated tools used by a proficient pilot can greatly help to manage workload, and thus, allow pilots to focus their mental abilities on items such as planning ahead and retaining situation awareness.

However, there can be a dark side to automation. The CEO of Microsoft, Bill Gates, purportedly once said, “Automation applied to an efficient operation will magnify the efficiency, but automation applied to an inefficient operation will magnify the inefficiency.” Furthermore, in addition to becoming competent at flying the aircraft, modern pilots must also achieve a high degree of proficiency in operating and supervising the automated systems. Learning how to operate different components takes time, and building the proper memory to efficiently actuate components takes even more time. A single knob can have different functions depending on how you actuate the knob and can also mask your intentions from the other pilot on the flight deck. Figure 8-3 shows a pilot reaching for a knob on the flight guidance panel of an Airbus. Pilots who do not understand automation fully can easily expect one type of automated operation to occur but then be surprised by what actually occurs, a concept known as *automation surprise*.

FIGURE 8-3 Pilots are taught to look for an output to an input, meaning that the pictured pilot may be moving a heading knob but looking at a flight display instead of the knob to see the actual output of the change. (*Source: Authors*)

Since human error is the source of many accidents, it has driven the safety philosophy behind adding more onboard automation, but human error associated with designing and then using automation must also be considered. It may seem to make sense to eliminate the human from operations, and therefore prevent accidents because of no human error, but humans are always involved in everything, including autonomous unmanned aerial vehicles. After all, people design unmanned aircraft, repair them, and oversee their operation. Errors can be introduced at any point in the cycle. Automation design philosophies need to consider striking the right balance between automation and humans because the two are complementary factors for providing flight safety.

These are challenging safety areas since accidents from human error in automation can be as inadvertent as a typo in a document. Many automation functions rely on a data-in, data-out structure. The output produced by the automation is directly tied to the input provided by the operator. The concept

that erroneous data input will produce inaccurate outputs is sometimes referred to by the expression *garbage in, garbage out*. Even a miniscule error could potentially cause a whole system to fail. To address such high stakes, some pilots treat data entry as a *sterile operation*, meaning that crew working on any type of data entry should not have distractions such as nonpertinent conversations with other crewmembers during the data entry operation. Their attention should be solely devoted to their work to prevent them from making inadvertent errors.

Emirates Flight 407 is an example of how the entry of a wrong number can have a huge impact. In 2009, the crew of Flight 407 narrowly avoided a crash during takeoff from Melbourne, Australia after someone accidently typed the weight of the plane as 262.9 tons, instead of 362.9 tons, thus resulting in the inaccurate calculation of the takeoff speed. As a result, the aircraft failed to climb once airborne and hit structures at the end of the runway before managing to gain altitude and return for a safe landing. The future of automation training should include novel concepts such as the idea of *no secret typing*, meaning that all key data inputs into automation must be cross-checked by both pilots.

Future safety improvements to the design of automation for flight deck use will require successful adoption of basic safety principles. First, there should be procedures and checklists that are an extension of company philosophy and operating procedures for the correct amount of automation to use in different flight situations. These items can help users know what to do, for example, in the event of an automation failure. Second, aircrew should rely on training and experience to identify a correct course of action in the event of abnormal or emergency situations. They should be able to make these decisions independent of automation in the case they need to rely on basic aviation principles. Similarly, pilots should work to retain basic hand-flying skills so they can still safely operate the aircraft if an automated system fails.

NEW FLIGHT DECK ENHANCEMENTS

Aircraft manufacturers strive to continuously improve human–machine interfaces, such as evidenced with the Boeing 777 and its new Boeing 787 “Dreamliner” aircraft. The layout of the Boeing 777 flight deck is similar to the Boeing 747-400 and has the following systems:

- Glass cockpit, three axis digital fly-by-wire flight control system.
- Flight, navigational, and engine information is presented on six large display

screens with advanced *liquid crystal display (LCD)* technology.

- An integrated Airplane Information Management System which provides flight crews information regarding the overall condition of the aircraft, maintenance requirements, and key operating functions.
- Ground maneuver camera system with video views of the nose and main landing gear to assist the pilot with ground handling when maneuvering at the gate area.

The Boeing 787 "Dreamliner" retains operational similarity with the B-777, including fly-by-wire with a control yoke, and has the following systems:

- The display screens are twice as large as the B-777, providing additional situation awareness to the flight crew. An avionics full-duplex switched Ethernet is used to transmit data between the flight deck and aircraft systems.
- New dual HUDs which allow the pilots to view critical flight data on a transparent display looking forward through the windscreen instead of down into the instrument panel.
- New dual electronic flight bags (EFBs) which are the digital equivalent of the bulky pilot's flight bag. This includes all maps, charts, manuals, and other data for the "paperless cockpit."
- New electrical architecture which replaces bleed air and hydraulic power sources with electrically powered compressors and pumps. This improvement saves weight and enhances efficiency.

Competition between Boeing and Airbus remains high for new aircraft orders.

The Airbus A-380 flight deck uses a similar layout to other Airbus aircraft and has the following systems:

- Improved glass cockpit and fly-by-wire flight controls linked to sidesticks as in the past, with improved LCD cockpit displays.
- Two primary flight displays (PFDs) dedicated to critical flight information, and two MFDs which display navigation route, moving map, weather, and other information. These MFDs are new to the A-380, providing an easy to use interface with the FMS.
- Similar to the Boeing 787, the A-380 uses an integrated modular avionics system with a full duplex switched Ethernet to transfer data to the aircraft systems.
- The EFB, which is essentially a means for producing a paperless cockpit, is

called a network systems server which stores data such as equipment lists, navigation charts, performance calculations, and the aircraft logbook.

The Airbus A-350 is the latest European aircraft following in the wake of the super jumbo A-380 development. Its flight deck has the following enhancements:

- Large LCD screens with two central displays, a single primary flight and navigation display with an onboard information screen, plus a HUD on the windscreen.
- The A-350's integrated modular avionics system manages many additional critical aircraft functions such as the landing gear, fuel, brakes, pneumatics, cabin pressurization, and fire detections systems.

CREW ALERTING SYSTEMS

The Boeing 737 introduced a very simple but elegant and effective crew monitor and alerting system. Almost all of the airplane's system controls are located overhead and are outside the normal line of sight of the two pilots. When all systems are "on" and operating, no caution lights are observed. In the event of loss of equipment, an amber light annunciates the condition on the overhead panel. The loss is also repeated on master caution lights on the glare shield in front of each crewmember and in small caution panels also on the glare shield. The panel annunciation identifies the system affected and the location of the system controls overhead.

Since this was a new scheme at the time of certification, it got a lot of attention by the certification authorities and designers. To make sure that airplane system operation was not an inordinate burden and did not substantially increase workload for the flight crew, many hours were spent in the simulator and during certification flight testing to measure the time spent on airplane subsystem operation. The result of such attention workload is that less than 1% of the crew's time from takeoff to landing is spent on system operation, including during the deliberate equipment malfunctions that were simulated by the certifying agency. This careful attention to system detail design and improvements in monitoring capability has been used for virtually all jet models subsequent to the Boeing 737.

GROUND-PROXIMITY WARNING SYSTEM. Since the advent of powered flight, inadvertent ground or water contact has been a worldwide problem. While much

early effort went into avoiding such accidents, no major advance occurred until introduction of the ground-proximity warning system (GPWS) in the early 1970s. Although there has been a marked reduction in controlled flight into terrain (CFIT) accidents since then, they still occur with distressing frequency and have accounted for up to 75% of worldwide fatalities on commercial transports. For the air carrier fleet, there are two primary reasons CFIT accidents occur: either (1) the airplane did not have GPWS (or it was inoperative) or (2) the crew received the appropriate GPWS alert but chose to ignore the alert. The Flight Safety Foundation (FSF), along with others, has an aggressive program to essentially eliminate CFIT accidents.

The *Enhanced* GPWS, termed EGPWS, is an advanced terrain warning system used in most modern commercial airline fleets. The EGPWS improves situation awareness and increases warning times by using a terrain database that compares actual location of the aircraft to terrain in the database and uses a "look ahead" feature to detect what terrain ahead of the flight path may pose a risk.

TRAFFIC COLLISION AVOIDANCE SYSTEM (TCAS). This is an electronic aircraft collision warning system to help prevent dangerous midair collision accidents, which as one might imagine are often associated with great loss of life. Typically, TCAS requires mutual "Mode S" transponder technology which automatically communicates with other aircraft independent of ATC systems to display the relative position of other such transponder equipped aircraft. Upon detecting an intruder aircraft, TCAS issues a traffic advisory or resolution advisory to the flight crew to climb or descend as necessary to avoid the other aircraft. The latest version of the system is TCAS II, Version 7.1, which has been endorsed by ICAO and several leading regulatory agencies. Implementation of this improved TCAS version is underway and provides enhancements such as the reversal of issued instructions in case one of the aircraft does not follow the originally issued instructions.

ENGINE-INDICATING AND CREW-ALERTING SYSTEM. The engine-indicating and crew-alerting system (EICAS, or ECAM for Airbus aircraft) is a digital computer system which monitors and indicates propulsion and airplane subsystem information for the operation and maintenance of the airplane. EICAS/ECAM interfaces with many airplane components and subsystems. Discrete inputs are implemented in a hierarchy that reflects operational and maintenance requirements:

- Flight crew alert messages duplicate dedicated subsystem information (usually indicator lights) elsewhere in the flight deck.
- Status and maintenance messages provide lower priority information on the condition of many subsystem components.

New Airbus and Boeing aircraft models have improved EICAS/ECAM to enhance functionality and reduce display footprint on the flight deck. Each manufacturer has its own strategies for engine indications and crew alerts, but all perform essentially the same basic functions.

AIRCRAFT COMMUNICATIONS ADDRESSING AND REPORTING SYSTEM

The Aircraft Communications Addressing and Reporting System (ACARS) is a communication datalink system that sends messages, using digital technology, between an airplane and the airline ground base. The operational features of ACARS equipment and the ways in which ACARS is used in service vary widely from airline to airline.

There is nothing new about sending messages between the airplane and the ground. What makes ACARS unique is that messages can be sent, including fuel quantity, subsystem faults, and air traffic clearances, in a fraction of the time it takes using voice communications, in many cases without involving the flight crew.

The Aircraft Communications Addressing and Reporting System relieves the crew of having to send many of the routine voice radio messages by instead downlinking preformatted messages at specific times in the flight. These may include the time the airplane left the gate, liftoff time, touchdown time, and time of arrival at the gate. In addition, ACARS can be asked by the airline ground operations base to collect data from airplane systems and downlink the requested information to the ground.

Each ACARS message is compressed and takes about 1 second of air time to transmit. Because of the automatic reporting functions described above, the number of radio frequency changes that flight crews must make is reduced on ACARS equipped airplanes. Sending and receiving data over the ACARS network reduce the number of voice contacts required on any one flight, thereby reducing communication workload errors and costs. Such messages were previously transmitted via voice by one of the pilots and often occurred during very inopportune moments of high workload.

The accurate reporting of event times, engine information, crew identification, and passenger requirements provides for a close control of any

particular flight. Airplane system data, such as engine performance reports, can be sent to the ground on a preprogrammed schedule, or personnel on the ground may request data at any time during the flight. This allows ground personnel to observe the engines and systems and can alert them to problems to be investigated.

Improvements in ACARS technology have been implemented in approximately 2,000 aircraft to transmit ACARS messages and data communications from air traffic controllers known as *Controller Pilot Data Link Communications (CPDLC)*. Voice communications are easily misunderstood, and voice frequencies are easily overloaded. CPDLC was proposed by FAA as a new strategy to cope with the increased demands on ATC and has proven very effective and efficient during operations in busy en route airspace.

FLIGHT MANAGEMENT SYSTEM

The *flight management system (FMS)* is an integration of four major systems: the flight management computer system (FMCS), the digital flight control system (DFCS), the auto-throttle (A/T), and the inertial reference system (IRS). The basic functions of the FMS are as follows:

- Automatic flight control
- Performance management
- Precision navigation
- System monitoring

The FMS is designed to allow crew access to the total range of aircraft performance, navigation, and advisory data computation capability at any time and in any flight control mode. For example, when the airplane is under manual control, the pilots, at their option, can get flight optimization data from the flight management computer and appropriate target airspeeds.

The flight management computer is a major innovation in the FMS design. In addition to navigation, it performs real-time, fully automatic performance optimization and can control the airplane through the flight control system, including the auto-throttle. While crews currently determine the most efficient speed and altitude by using the flight operations manuals and calculators, this function is usually performed only periodically. Further, because it is a digital system, the software and programmable databases in the FMS provide the adaptability and growth needed for present and future airline operations, particularly as navigation and ATC systems evolve.

MULTIPLE FLIGHT CONTROL COMPUTERS

On the newer-generation aircraft, elevator/aileron computers (ELACs) have primary control of elevators and ailerons and perform the computations for spoilers and yaw damping. One ELAC is active while the other is a backup.

Spoiler/elevator computers (SECs) provide primary control of spoilers. If both ELACs fail, the SECs also provide backup control of roll and pitch via spoilers and elevator.

Flight augmentation computers (FACs) control rudder for turn coordination and yaw damping. They also compute limits for the flight envelope, wind shear, and speed information displayed on the primary flight display.

Multiple, redundant computer flight control systems ensure that no single failure of an electrical, hydraulic, or flight control component will result in a reduction in operational capability.

CENTRAL MAINTENANCE COMPUTER SYSTEM

One technology that is able to assist in ensuring the operational status of complex systems is the *central maintenance computer system (CMCS)*. This technology can collect, display, and provide reports of fault information and test airplane systems. It provides ground maintenance personnel with a centralized location for both testing and access to maintenance data. The net result is a decrease in airplane turnaround time and an increase in dispatch reliability over previous-generation airplanes.

The CMCS was developed to monitor and troubleshoot the complex and integrated systems on the Boeing 747-400. It was also created to centralize ground testing, fault information storage, and real-time data monitoring. In previous-generation airplanes, testing, troubleshooting, and fault isolation were confined to a system-by-system approach, and faults that affect multiple systems were often difficult to isolate. Because so many systems on the Boeing 747-400 are interdependent, a fault in a single system can ripple through several other systems. Since the CMCS is linked to all major systems, it can provide simultaneous fault monitoring for related systems and can reduce multiple fault indications to a single fault.

The latest Airbus system for real-time aircraft maintenance is known as *AIRcraft Maintenance ANalysis (AIRMAN)*, which is an intelligent software system designed to optimize maintenance and minimize aircraft turnaround time

on the ground. AIRMAN constantly monitors the health of the system, tracks maintenance that has occurred on the aircraft, and has the clever feature of prioritizing troubleshooting steps by likelihood of success.

MODELING, DESIGN, AND TESTING TOOLS

Airplane design and technological progress seen in this century could not have happened without parallel advancements in computing capability. This was no coincidence, for in many cases, computer science was trying to solve airplane technology problems. Major breakthroughs for the computer (and all avionics for that matter) were the vacuum tube, the transistor, and the microprocessor.

The computer advancements made to date are what enabled not only all the onboard and support avionics systems but also all the analysis and testing that go into them. It is not possible to cover all this technological progress, as it has been explosive on all fronts. The important part of incorporating any technology is to first make sure it has been analyzed and tested thoroughly. Some of the technologies that have made contributions to commercial aviation safety are discussed next.

COMPUTATIONAL FLUID DYNAMICS (CFD)

Computational fluid dynamics (CFD) methods have been used extensively in the design of all new-generation aircraft. Advances in supercomputing technology over the years have allowed CFD to solve problems of greater relevance to aircraft design. Use of these methods allowed a more thorough aerodynamic design earlier in the development process, allowing greater concentration on related operational and safety-related features.

WING DESIGN. The ability of CFD to do the inverse problem, meaning to determine an optimal geometric shape in order to achieve a desired flow, revolutionized the transport wing design process. Since the Wright brothers, wing design had been a "cut and try" operation, which is an expression more widely referred to as a trial and error approach. The "try" would take place in the wind tunnel or in flight. The advent of sufficiently powerful computational methods allowed some of the try to be shifted to the computer. The "cut" was the designer shaping the wing based on experience and intuition. CFD allows a new approach in which the design engineer specifies to the computer the aerodynamic pressures desired on the wing, and the CFD code computes the geometric contouring of the wing surface that will produce those pressures. The

engineer does all the design works, the initial evaluation with CFD, then picks the best candidates, and then builds the best wind-tunnel models to test the new design.

This inverse design technique was first used in the development of the Boeing 777, which sets a new standard for all future aircraft to follow, allowing achievement of a level of aerodynamic performance not otherwise possible in a time-constrained development program. The CFD methods used for this application were based on nonlinear potential equations coupled with boundary-layer equations to account for viscous effects. The key to this use of CFD was the ability to model enough relevant physics and gain quick turnaround from initial geometry to a completed solution. The resulting wing designs are thicker and lighter than their previous counterparts. These characteristics allow wings with greater span or less sweepback. Both features are conducive to better low-speed (landing and takeoff) performance, improved safety margins, and reduced aircraft noise.

Today, CFD is being used to better address the diverse requirements for nacelle design for cruise, engine-out second-segment climb, and engine-out *extended-range twin-engine operations (ETOPS)*. Nacelle design is being optimized to minimize drag at cruise conditions and provide acceptable engine-out drag for second-segment climb and ETOPS. Engine-out drag is not the only criterion of merit. If external flow separation occurs, the separation wake could impinge on other aircraft components, causing premature buffeting of the aircraft, perhaps indicating to the pilot that the aircraft is approaching stall conditions. If it is severe enough, the pilot might be inclined to reduce the angle of attack—a situation not desired during takeoff or climbout. CFD has become a very valuable tool for the designer to provide additional safety benefits that might not otherwise have been feasible.

WIND-TUNNEL BENEFITS

Today, *wind-tunnel testing* complements the computational fluid dynamics tools, which focus efforts to a narrowed field of configuration options. During development of the Boeing 767 in the late 1970s, the manufacturer conducted tests in 15 tunnels in four countries for more than 20,000 hours, conducting 100,000 data runs. Each run consisted of recording an average of 65 independent parameters at approximately 25 different aircraft attitudes. In that Boeing 767 program, more than 100 variations of the wing design and untold numbers of different flap and slat positions were tested. Despite intensive use of CFD, the test program for the Boeing 777 involved about 20,000 hours of wind-tunnel

testing up to the first flight.

The value of wind-tunnel testing goes beyond optimization of wing designs and performance. The results contribute to information about safety involving load determination for structural design, simulator database development, stability and control characteristics for both normal and failed configurations, and aircraft anti-icing control. The effective and efficient integration of propulsion systems onto the airframe is served, in part, by powered models that provide simulations of installed engines’ flow fields.

FLIGHT SIMULATION

The *flight simulator* was recognized very early as a valuable tool in improving aircraft safety. It owes a lot to the pioneering efforts of Ed Link. Early in the initial transition of crews from props to jets, a number of training accidents occurred, particularly during engine-out training. It endangered not only those in the airplane but also those on the ground. The technology that allowed this hazardous training to occur in a simulated environment on the ground was a great benefit to flight safety.

Development of the simulator took two parallel paths, one for engineering evaluation and the other for flight training. Each benefited the other. The engineering simulation allowed the engineer and the test pilot to evaluate design options during design and to define the best operating procedures. It has also been used to evaluate accident and incident data to better understand what might have gone wrong and to find solutions.

At first, simulators were very crude. The engineering simulators were analog and could fly the initialized flight condition on instruments only. Later, a model board was constructed to represent a bird’s-eye view of a large ground area using a miniature TV camera and closed-circuit TV that “flew” over the landscape model to provide an accurate view out of the cockpit window. This feature greatly improved the evaluations that one could perform, but it had limitations. Computer-generated imagery (CGI) was the real breakthrough. It allowed weather and a variety of airports to be evaluated. This technology continues to advance and is providing more and more realism with full flight simulators featuring three-axis motion platforms and 360-degree, outside-world visual projections.

FLIGHT TEST

The ultimate test of an airplane before it enters active service is when it goes

through flight testing and is subjected to the real-world environment. Flight testing has had to advance in four areas to keep pace with the jet airplane's advanced performance, expanded flight envelope, and the advanced technology incorporated into the airplane systems. These four areas include the following:

1. New flight-test techniques
2. Improved accuracy of instrumentation
3. Improved data-recording systems
4. Real-time monitoring and data analysis

These advances have made it possible to conduct increasingly accurate and thorough tests to ensure that the airplane is ready for service. Typical of such tests is the takeoff minimum unstick speed, abbreviated V_{MU}, which is the minimum airspeed at which an airplane can safely lift off the ground and continue takeoff. This test demonstrates the takeoff performance margin existing at unstick (takeoff) speed, ensuring that the airplane will not encounter a hazardous condition such as loss of control or failure to accelerate. This is one of the key tests to ensure that engine thrust is maintained; the control and flap systems function as designed; and control and flap systems provide the airplane with the low-speed, high-angle-of-attack controllability needed for safe operation. This test is also used to establish required operational parameters for takeoff field length. Flight tests such as this one have greatly contributed to the safety of the commercial airplane.

Accident/Incident Investigation

The industry has always devoted a lot of effort to the technologies involved in finding causes of incidents and accidents. The *flight data recorder (FDR)* and *cockpit voice recorder (CVR)* are indispensable tools in this task.

Substantial progress was made during 1987 in the NTSB's goal of persuading the FAA to require more and better cockpit voice recorders and flight data recorders aboard aircraft. However, efforts by the NTSB to upgrade requirements for the use of FDRs and CVRs to take advantage of newly available technology have often faced a long, uphill battle. Over the years, the NTSB had difficulty persuading the FAA to improve recorders on larger commercial jets and expand their use on commuter and some corporate aircraft, despite the proven value of recorders as a vital tool in accident investigations.

The FAA had issued a notice of proposed rulemaking to upgrade recorder requirements but failed to act on it for more than 2 years, despite NTSB

prodding. On March 25, 1987, however, the Secretary of Transportation announced a requirement for installation of CVRs on newly manufactured turbo propeller commuter aircraft carrying six passengers or more and having two pilots. The Secretary also called for installation of digital flight data recorders on older jet aircraft, replacing the foil-type versions then required. The announcement came after a commuter plane accident at Detroit Metro Airport on March 4 of that year, which dramatically helped focus congressional and public attention on the stalled flight recorder rulemaking. Just 2 weeks after the accident, a congressional panel approved report language directing the FAA to "take immediate steps to require the installation of CVR and FDR devices on all commuter aircraft in line with NTSB recommendations."

The number of FDR data channels and the crashworthiness of these vitally important records have increased significantly. The early generation of FDRs only recorded time, altitude, airspeed, vertical acceleration, heading, and the radio transmission event marker. The number of parameters has now increased so that today, with all-digital avionics systems onboard the new airplanes, a more detailed record can be made and stored for a longer time. This area is another way in which digital avionics contributes to aircraft safety.

The Boeing 787 Dreamliner is the first aircraft equipped with *enhanced airborne flight recorders (EAFRs)*, a combined cockpit voice and flight data recorder (CVR/FDR) with crash protected memory, and the capability to record datalink messages and cockpit imagery. In 2002, the NTSB added crash protected image recorders to its Aviation Most Wanted Safety Improvement List of items needing urgent attention by the FAA; therefore, development of cockpit image recorders will be a future issue in the area of accident investigation.

CONTROL STRATEGIES TO MANAGE THREATS AND ERRORS

Effective control strategies to manage threats and errors include engineering-based tools associated with the aircraft such as cockpit automation, instrument displays, or warning devices. For example, the GPWS is a so-called "hard" defense mechanism to prevent controlled flight into terrain with visual and audio warnings to "pull up." A yoke "stick shaker" or stall warning horn would be another example of an engineering control strategy to warn pilots of low air speed and possible stall situation.

There are other control strategies which are more administrative in nature. The so-called "soft" defenses such as checklists, rules and regulations, standard

operating procedures, etc., are used to direct crewmembers to take appropriate action under a given set of circumstances. Using CRM, LOSA, and Threat-and-Error Management (TEM) training concepts, modern airline crews are now taught the newest techniques and communication skills to avoid the human error entirely; trap it from spreading into an undesired aircraft state; or finally, mitigate the consequences of the error through anticipation, error recognition, and ultimate recovery from the undesirable human error problem.

AIRBUS AND BOEING DESIGN STRATEGIES

With the rapid growth in microprocessor technology in the past three decades there has been a temptation on the part of some designers to build very complex systems based on the rationale that the systems could operate automatically. There are two major fallacies in this argument. First, almost no major system on an aircraft truly operates fully automatically. Systems must be initialized or set up by the human, decisions about operating modes must be made, and then the systems must be monitored by humans for obvious reasons. Second, in the event of the failure of automation, it always falls to the human to operate the system. This responsibility cannot be avoided or designed away. If the complexity of the system is unbridled, then the crew may not be able to perform their duties effectively or take over in the event of equipment failure.

In response, many design engineers with human factors sophistication have recognized that simplification offers an attractive alternative to automation. If the system can be simplified, there may be no need for complex automation, and the same goal can be achieved without placing the human in a potentially hazardous position. An example is the fuel system on a multiengine aircraft. Those favoring automation would find no problem with creating a complex tank-to-tank and tank-to-engine relationship, as long as its management could be automated. If, for example, a fuel imbalance were created, automatic devices would detect the imbalance, determine a remedy, open the required transfer valves, and turn on the appropriate pumps to restore the proper balance. No human intervention would be required.

This example represents a philosophical difference between two major aircraft manufacturers—Airbus and Boeing, as previously expressed in the chapter. The Airbus general approach has been to remove the pilot from the loop and turn certain functions over to sophisticated automation. Aircraft compliance with the input is automatic—the computer systems do not ask for the crew's approval. Boeing's approach, however, is never to bypass the crew: Sophisticated devices inform the crew of a need and, in some cases, a step-by-

step procedure; but in the end, it is the crew who must authorize and conduct the procedure. Boeing is a strong advocate of simplification before automation. Their designers would look to a less complex relationship. An example would be fewer tanks to feed the engines, creating fewer tank-to-tank and tank-to-engine requirements, requiring less management by the crew and fewer opportunities for human error.

One of the potential difficulties with highly automated systems is that onboard computers may, unknown to the crew, automatically compensate for abnormal events. Efficient automatic reaction to abnormal events and conditions sounds attractive, but there is always a limit to the system's capacity to compensate. When automation is reacting to a worsening condition without the crew's knowledge, this can lead to a situation where it may be too late for the crew to override the system and thus prevent a catastrophe,—hence our theme to Chapter 4, "Humans as the Solution."

FLIGHT DECK STANDARDIZATION

It is desirable to ensure that the automation and systems operated by pilots are relatively similar between different types of aircraft in a given airline. Doing so reduces training costs and prevents negative transfer of habit patters as pilots transfer between aircraft types during a career. Maintenance costs are also reduced from such an approach. During periods of rapid expansion of aircraft inventories and pilot personnel, there is frequent movement between aircraft as pilots bid for more lucrative or convenient assignments, more modern aircraft, or more desirable bases. Some airline labor contracts limit the rapidity with which pilots may bid a new seat; others do not.

Most flight deck hardware is peculiar to the type of aircraft. However, certain flight deck hardware could be common to most or all models operated by a carrier; examples are radios, flight directors, certain displays, area navigation equipment, and weather radar. Other examples would be devices added after the original manufacture (e.g., TCAS, ACARS). When the carrier has the opportunity to purchase these add-on units, a common model will most likely be chosen for all the reasons stated above.

Where differences already exist between fleets, the airline may intervene by standardizing procedures throughout the airline. For example, some airlines have invested in a common airline-wide model of the flight director, which is a type of automated information presentation for pilots to help with precise aircraft control.

Between-fleet standardization, if it involves retrofit rather than new

equipment purchase, will be extremely costly and its safety benefits may be modest compared to within-fleet standardization. Nonetheless, when pilots move rapidly through the seats of various aircraft or complete training for one aircraft and then return to another while awaiting assignment to the new aircraft, fleet standardization of flight deck hardware deserves inclusion in the list of intervention strategies against human error.

Within-fleet standardization is a far more critical issue. Long before the Airline Deregulation Act of 1978, carriers purchased aircraft from one another, thus generating mixed aircraft configurations within fleets. With the coming of deregulation, the pace of mergers and acquisitions, as well as used equipment purchases and leases accelerated rapidly causing a safety issue regarding flight deck configuration. These differences included different displays (e.g., various models of flight directors), warning and alerting systems (e.g., a host of altitude warning systems with various trigger points), every imaginable engine configuration, controls in different locations, various directions of movement of switches, and various operating limitations. One carrier, which had been through a number of mergers and acquisitions of other DC-9 operators, had eight different models or locations of altitude alerts. It later invested a very considerable sum to standardize the flight deck of its DC-9 fleet. Within-fleet standardization is considered a high-priority item by line pilots, airline pilot unions, and safety committees. Southwest Airlines is a good example of a successful flight deck standardization program, focusing on the modern Boeing 737 as its basic configuration.

FLIGHT DECK AUTOMATION AND PRECISION NAVIGATION

In today's modern commercial aircraft, computer technology and the "glass cockpit" have become the norm. Navigation is accomplished electronically on moving maps using the latest techniques to enhance the situational awareness of the pilot. Nevertheless, as we have learned, the human error element is always present and must always be actively monitored by the crew. A good example of a human error occurred onboard a Boeing 767 preparing to depart Atlanta for Miami. The clearance included TEPEE (note spelling) as a GPS waypoint, representing an intersection near Tampa, Florida. The captain entered TEEPE (note the different spelling) into the route page of the control display unit (CDU). Because there is a TEEPE intersection in Texas, the CDU dutifully accepted the erroneous spelling and established it as a waypoint on the route from Atlanta to Miami. The sudden shift in course to the west-southwest toward TEEPE from the southward course toward TEPEE was immediately evident to

the crew. A non-EFIS aircraft with the same CDU FMS (such as some models of the Boeing 737-300) would not have provided this form of error detection capability. The crew would have had to detect the error by some other check or the hard way when a violation had been issued by an air traffic controller noticing the navigational deviation.

Once the aircraft system properly displays an abnormal condition, there must be an effective means of removing it and allowing the system to recover. The system must not permit irreversible errors. With traditional aircraft, this was not a problem, since working with less sophisticated systems the pilots were closely coupled to the machine and they could usually detect and correct an error or undesirable system state quite quickly. The advent of highly sophisticated automation raises the question of escaping from error and system recovery. Generally, the problem is not that the error is irreversible but that a complicated recovery process can be difficult, time-consuming, and possibly error-inducing.

Nevertheless, the modern FMS offers some novel features for protection against human error. It can store and process a vast amount of information typically contained in manuals, checklists, performance charts, flight plans, weather reports, documents, and paperwork of all sorts. This information can be displayed to the crew in text, numeric, and graphic forms on selected pages of the control display unit, the glass instrument panels, and elsewhere. Some of the information is automatically displayed, requiring no request from the crew (e.g., the wind vector on the navigation display); other information is available in the FMS on demand through pilot selection of the correct CDU page. The display of certain valuable information, such as suitable emergency airfields, is switch selectable. Finally, if the FMS detects an abnormal computer condition, a brief message can be displayed in the "scratch pad" line of the CDU, and the pilot is alerted on two other displays that an FMS message is waiting. An example would be a request for a waypoint "not in the database."

The Boeing 767/757 and the glass cockpit aircraft that followed possessed rudimentary forms of computer-based error elimination and protection. The Airbus A-320, introduced in 1988, took error protection a step further. The fly-by-wire feature offered the opportunity to fly maneuvers, such as maximum safe angle of attack (AOA) for wind-shear escape maneuvers, with no danger of entering a stall. The computer would simply stop the aircraft's increase in pitch short of its computed safe AOA. If the pilot continued to pull back on the stick, no more nose-up pitch would be allowed by the aircraft. An intelligent computer interposes an electronic line of defense between the pilot's control and the aircraft's control surfaces. Incidentally, such a system that has the capability of controlling and correcting an error is referred to as an *error-resistant or error-*

tolerant system.

Other EFIS aircraft, such as the Boeing 757/767, offer escape guidance on the *attitude indicator* in the form of a target line for optimal nose-up pitch. In contrast with the approach taken in the A-320 design, the pilot always remains in the loop in the Boeing aircraft. The pilot controls the pitch angle; the computer merely computes and displays the commanded nose-up pitch.

These two approaches emphasize not only disparate views of cockpit design but also basic philosophical design differences previously mentioned in this chapter. The Airbus family of aircraft essentially allows the pilot to pull the control stick all the way back and let the computer find the maximum angle of attack that will avoid a stall. Other EFIS-equipped aircraft depend on the pilot to follow the wind-shear escape guidance cues. Each approach has positives and negatives, so it is hard to say which approach is more effective. Only time, experience, years of accident investigation statistics, and academic studies will settle that question.

NEWER AIRCRAFT TECHNOLOGIES

The technological opportunities for continued improvement in flight safety are as good as ever. The analytical tools, computing capability, simulation, and testing capability all far exceed those of the past, and new technologies are continuing to unfold. These opportunities are challenging to all engaged in the aviation safety community.

Of all the technologies available for improving safety while providing substantial gains for future growth, system capacity, and efficiency, electronic technology appears to have the most immediate promise. Accident statistics continue to bear out the fact that the aircraft manufacturers need to assist flight crews in doing their tasks while improving efficiency of operation. Chip-level redundancy combined with fault-tolerant design will provide far greater reliability levels for essential and critical functions. Aircraft safety and total system capacity and efficiency will undoubtedly be enhanced in the future. Boeing and Airbus are already using a number of these features on their next-generation aircraft.

WEATHER DETECTION

Weather remains a major cause of delays and accidents. Real-time, accurate knowledge of the weather ahead is required. Aircraft must be able to detect weather conditions; alert the flight crew to avoid dangerous situations; and

weather conditions, alert the flight crew to avoid dangerous situations, and effectively cope with turbulence, precipitation, and wind shear.

Today's airborne weather radar technology needs improvement, as does the training that pilots receive on adjusting radar settings to deliver desired information for weather avoidance. Furthermore, the current air carrier fleet is often limited to a simple view of weather, and we need a real-time, "big picture" integrated display. The future will likely bring advanced airborne weather radar with vertical as well as cross-sectional views. Ground and satellite weather detection improvements made available on the flight deck will combine to enhance flight planning, performance, and safety.

Onboard system enhancements to aid the pilot in unexpected wind-shear encounters are being incorporated on current aircraft. These wind-shear alert and guidance systems are being combined with crew training, improved ground-based alerting, and weather radar systems. Emphasis is on detection and avoidance of hazards occurring along the flight path. If wind shear is unavoidable, the wind-shear system quickly alerts the crew and provides pitch attitude guidance to effect the most optimal escape maneuver. Improvements are also planned to the current ground-based, low-level wind-shear alert system. Terminal Doppler weather radars will continue to be installed at critical airports.

Communication and Navigation Systems

As will be discussed at length in Chapter 10 on air traffic system technologies, aviation is transitioning toward a new communications, navigation, and surveillance/air traffic management (CNS/ATM) environment. This will inevitably change the way pilots communicate and navigate.

For starters, most ATC messages would be sent by datalink to and from the airplane rather than by voice. Navigation would be based more on satellites than on land-based navigation aids, and traffic surveillance would be achieved by networking tactical information among all aircraft. The benefits of these changes, particularly to the airlines, are potentially enormous. A global navigation and communications system will allow for higher traffic density and improved safety, while at the same time enabling airplanes to fly at optimum altitudes and on more direct routes. Voice mode will still be essential for emergencies and other nonstandard communication, but for the most part, tomorrow's flight decks will be much quieter without the perpetual stream of ATC chatter heard through radiofrequencies on traditional flight decks.

As envisioned, the transition from today's airspace environment, in which routes are rigidly assigned by controllers on the ground, will move first to a

system in which flight plans are originated in the airplane and approved by controllers on the ground. Then at some point perhaps flight plan changes will be initiated in the airplane in real time and simply monitored from the ground.

But this does not mean that the conventional terrestrial navigation systems will disappear overnight. In the United States, the FAA plans to keep very high frequency omnidirectional range (VOR) and distance-measuring equipment (DME) in operation for at least another decade. During this time, pilots' dependency on the equipment will decrease as more flight operations use satellites to navigate. However, the susceptibility of GPS to interference probably means VORs will be around for a long time to come, as most observers believe.

The future will bring increased capabilities, some of which will include digital communications to accommodate high-speed data to and from the cockpit, WAAS/GBAS approaches and landings, GPS-based en route navigation, and automatic dependent surveillance broadcast (ADS-B) procedures allowing new sophistication in flight tracking and traffic avoidance. Also during this time, today's VHF voice communications will slowly give way to increased digital communications, and surveillance systems will become more sophisticated, moving away from today's Mode S transponders, ATC surveillance radar, and Traffic and Collision Avoidance System (TCAS) to the modern ADS-B system of the future. The result will be a better near-range picture of traffic, and therefore, call for far less callouts of other aircraft by air traffic controllers.

There is a tremendous need to provide data to the flight deck from the ground. In the future, digital communications are expected to make today's VHF communication radios obsolete, even those that are now undergoing updates for 8.33 kHz requirements in Europe. The new infrastructure will require radios that can transmit in both voice and high-speed digital formats. The *VHF Datalink (VDL)* Mode 2 system is already in operation, and the FAA has already proven the efficiency of the CPDLC system in high-density air traffic areas. ADS-B avionics that are under development include a *cockpit display of traffic information (CDTI)* feature that enables the pilot to "see and avoid" other aircraft electronically. Figure 8-4 shows an experimental NASA CDTI taking the place of a traditional flight deck navigation display, depicting a traffic conflict requiring pilot-selected de-confliction when flying under autonomous flight rules versus relying on ATC for de-confliction.

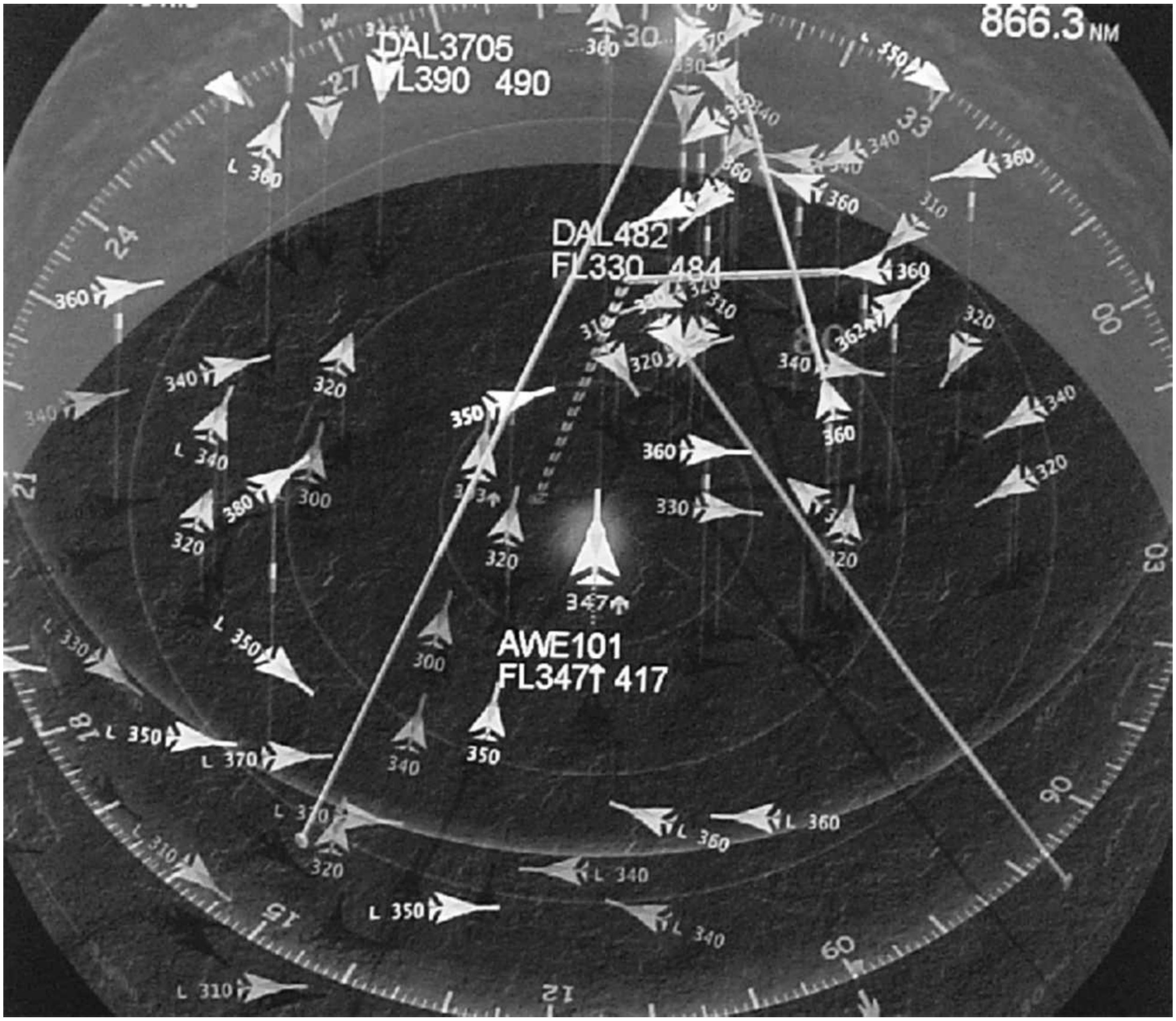

FIGURE 8-4 NASA experimental CDTI. (*Source: Authors*)

Using modern ADS-B technology, aircraft emit signals that tell its position to other similarly equipped aircraft in the area. This information is depicted visually on a display on the flight deck and will greatly enhance a pilot's awareness of the position of other ADS-B equipped aircraft and lead to safer operations. The United Parcel Service's (UPS) efficient use of CDTI at its hub in Louisville has proven that substantial fuel savings can also be gained by use of ADS-B en route descent technology.

By reducing dependency on voice transmissions, pilot workload will presumably be greatly reduced. For en route applications, communications via datalink will be implemented first. Most observers agree it will probably be at least a decade before we see heavy use of digital communications in the terminal area. The transition from voice to digital communications will evolve fairly

slowly, observers believe, first because pilots need to become more comfortable with the idea of sending and receiving information in this format. The second reason is because thousands of older airplanes will require new avionics to receive and send data via digital link.

Avionics makers must also develop new radios that can be updated through software changes rather than expensive hardware upgrades. If we have learned anything from the personal computer industry, it is that the new technology constantly being developed can quickly make yesterday's equipment obsolete. The challenge for aviation will lie in developing avionics systems that have reasonably long, useful lives at a reasonable cost.

The potential for change and innovation in the navigation and communications infrastructure is limitless, and when it finally evolves, the modern flight deck will be a markedly different place from what it is today.

FLIGHT DECK DISPLAYS

Most observers did not imagine that the LCD would replace the cathode-ray tube as quickly as it did. Advances in commercial LCD production, however, helped bring costs down, while avionics makers enhanced off-the-shelf products for unmatched levels of fidelity. Today, all new avionics suites for jets are being designed around large-format LCDs. Just how big the displays will grow depends largely on what happens in the market for commercial LCDs.

The future vision of avionics makers is to use displays that spread across the entire flight deck someday. Some are looking at new technologies such as gas-plasma displays or projection displays to meet this goal. For now, however, the LCD is the most cost-effective way to bring the information needed for tomorrow's flight environment to the flight deck.

Using LCDs, avionics makers plan to integrate terrain, traffic, and weather information and display it on top of charts and approach plates, which will provide a seamless source for information layered in such a way that pilots can better interpret the overall flight situation. Tomorrow's flight deck will be more dependent on sophisticated computer software that will greatly enhance the capabilities of the avionics, while at the same time adding to the complexity of computer systems. To help pilots better manage the technology, cursor-control devices, similar to a computer mouse, will be used at first to scroll through simple menus and later to plan entire flights. Figure 8-5 is an example of a multifunctional display showing superimposed, real-time weather and navigation information during Hurricane Irene in 2011. Displays such as this, which show a combination of aircraft, meteorology, and navigation information, are typical of

those being installed in many modern flight decks.

FIGURE 8-5 State-of-the-art flight deck display. (*Source: Authors*)

Head-Up Displays (HUDs)

Head-up displays will become much more commonplace in tomorrow's flight decks, experts believe, particularly if manufacturers can bring costs down. A number of HUD makers may shift their engineering focuses and begin looking at the use of smaller lenses and direct-projection HUDs, such as those used by the military in the C-17. This would eliminate the need for the large optics projectors and image collimators used today, making the systems far simpler to install and maintain.

Head-up displays present vital aircraft performance and navigation information to the pilot's forward field of view. The information on the HUD is collimated so that symbols appear to the human eye to be at infinity and overlaid on the actual outside scene. Figure 8-6 shows how symbols appear to a pilot

looking through the HUD. The use of HUDs is gaining broad acceptance in aviation as flight crews realize the tremendous benefits to situational awareness that they can provide.

FIGURE 8-6 The view through a HUD while parked on a ramp. (*Source: Authors*)

Also, use of the new *enhanced flight vision system (EFVS)*, a display that allows pilots to see through low-visibility weather, could become commonplace in the cockpit of the future. *Forward looking infrared (FLIR)* thermal cameras have been developed to display a real-world visual image to the cockpit allowing the pilot to “see” in very low visibility conditions. Additionally, HUD systems are also being developed to display new *synthetic vision system (SVS)* images. In contrast to the EFVS, SVS produces a computer-generated artificial image using moving map and terrain databases to provide a more realistic view of the outside environment. Recently, display researchers have even combined EFVS with SVS to improve the visual picture. Combining the real work reliability of the EFVS FLIR with the terrain and situational awareness of SVS could dramatically reduce issues associated with low-visibility approaches in the

future.

ELECTRONIC FLIGHT BAGS (EFBS)

In the near future, *electronic flight bags (EFBs)* will begin to show up with greater regularity on the flight deck. A number of avionics makers have already introduced such devices, which pilots would use to review charts and approach plates, perform weight and balance calculations, and plan flights, among other functions.

Eventually, with the inclusion of chart databases that can be viewed on the MFD and EFBs, paper may vanish from the flight deck altogether. Of course, the transition from a paper chart that the pilot can hold in his or her hands to electronic-only format will be slow for some operators, especially for airlines in developing world countries without the financial resources or technology to implement these changes.

NEXT-GENERATION FLIGHT OPERATIONS

In a NextGen environment, pilots would be released from the rigid discipline of being spaced in nose-to-tail time blocks, along less-than-optimum routes, and often at inefficient altitudes. Extended to its ultimate application, NextGen would embrace the airplane's complete operation, from start-up at the originating airport to shutdown at the destination after having flown a direct, nondeviating course, flying the optimal performance figures straight out of the airframe manufacturer's operating handbook.

To make this new era possible, operators will need to install new avionics, the most critical being based upon ADS-B technology. The current Mode S transponders will eventually take on a much more sophisticated role as ADS-B is implemented. Also required for NextGen will be datalink radios, which would be used to pass as much information as practical over discrete controller-pilot frequencies.

Once the transition to a NextGen-based traffic regime begins, observers believe airlines will begin updating the current fleet fairly rapidly. The technological challenges involved are large but not insurmountable, which means the future may be nearer than we realize. From a human factors point of view, major changes in NextGen flight decks also provide new opportunities for human error and significant training challenges.

ASRS EXAMPLES

As more aircraft incorporate automated features into the flight deck, more and more reports are appearing in the Aviation Safety Reporting System (ASRS) about the learning curve associated with new technology. The following two reports demonstrate the need for pilots to understand how advanced systems work in order for the systems to work as an aid to pilots versus as a contributor to human error.

In the first report, two pilots of an Embraer 190 jet experienced a track deviation when their Flight Management Computer (FMC) responded in an unanticipated manner when there was a runway change. They neglected to verify inputs to the FMC for the new runway and should have put the autopilot in a different mode to keep it on the correct arrival route. However, due to a quirk in the navigation system, the plane went back to the beginning of the arrival procedure by default as result of the runway change. This process, according to the pilots, was counterintuitive and very illogical. Future training programs should catalogue the prevalence of such quirks and train pilots to watch for such unexpected situations.

Another example involves a Boeing 737-800 flight crew missing an altitude constraint on the published flight plan before reaching the airport. ATC had cleared the plane to land on Runway 24R. The pilot changed the runway in the plane's automated system. At that time, the plane was on autopilot descending with the elevators controlling the pitch attitude of the aircraft to follow a programmed vertical path. However, after the new runway was inserted in the computer, the automation changed to have the elevators control the pitch attitude of the aircraft to control speed versus to follow the vertical path. Neither of the pilots noticed the switch from flying toward a vertical path to flying to a set speed since they were focused on the runway change. This was a lesson to both pilots that they need to monitor any changes to the modes being selected by the automation so that they always know how the aircraft is being flown. Remember the old adage: "Aviate, Navigate and Communicate" in that order. If all else fails, "Fly the aircraft."

CONCLUSION

It may seem obvious when you think about it, but commercial aviation safety is intimately connected to the design of the various aircraft that form the backbone of the transportation system. Over the past century, the industry has learned from many painful lessons and incorporated new knowledge into making aircraft both

safer and more efficient.

The jet age brought with it a significant increase in capabilities and reliability but also new challenges, such as structural fatigue and very long service life for aircraft. By leveraging knowledge from military jet programs, the manufacturers of commercial aircraft have been able to accelerate development of all the systems that make up the modern airliner, such as electronics, automation, structural resilience, and propulsion. Advancement has come via an evolutionary process, often prompted by painful accident investigation experience.

Some principles developed over half a century ago, such as fail-safe design, have become fundamental to current and future designs. Other principles and regulatory guidance for the design of aircraft for safety have stemmed from dramatic events, such as when the fuselage ripped open on Aloha Airlines Flight 243 due to the uncontrolled propagation of a crack, and ultimately resulting in the passing of the Aging Aircraft Safety Act by the U.S. Congress.

Different aircraft manufacturers can follow contrasting design philosophies, as evidenced in the approach toward automated flight envelope protections between Boeing and Airbus, where aircraft such as the A-320 use electronic lines of defense referred to as error-resistant or error-tolerant systems that prevent certain types of control inputs versus Boeing aircraft that present limit information but do not necessarily restrict pilot actions.

Modern flight deck designs must be developed with NextGen airspace requirements in mind, as illustrated by CDTI systems that allow pilots to self-resolve traffic conflicts and even plan their own spacing requirements in densely packed airspace. The pilots of the Embraer 190 and Boeing 737-800 featured in the ASRS examples show the importance of designing new automated systems so that their operation is transparent and intuitive.

Lastly, no matter how well we design aircraft, much of the safety value chain is formed by how well humans utilize the new technology. We have made extremely reliable and highly automated aircraft safety systems to the point where humans are unable to retain some basic skills associated with being a pilot. Figure 8-7 shows an increasingly rare sight on the modern flight decks of commercial airliners. Hand-flying a jet is on the extinction list of common pilot duties. So it is fitting that this chapter mostly speaks about designing aircraft but finishes by discussing the human part of the design equation.

FIGURE 8-7 The pictured pilot has his hands on the controls. Modern pilots are urged to hand-fly aircraft occasionally to maintain flying skills because autopilots do most of the flying today. (*Source: Authors*)

KEY TERMS

Aging Airplane Safety Rule (AASR)
Aircraft Communications Addressing and Reporting System (ACARS)
AIRcraft Maintenance ANalysis (AIRMAN)
Antiskid System
Auto Slat Gapper
Automation Surprise
Central Maintenance Computer System (CMCS)
Cockpit Display of Traffic Information (CDTI)
Cockpit Voice Recorder (CVR)
Computational Fluid Dynamics (CFD)
Controller Pilot Data Link Communications (CPDLC)
Electronic Flight Bags (EFBs)
Engine-Indicating and Crew-Alerting System (EICAS)

Enhanced Airborne Flight Recorders (EAFRs)
Enhanced Flight Vision System (EFVS)
Extended-Range Twin-Engine Operations (ETOPS)
Fail-Safe or Damage Tolerance Design
Flight Data Recorder (FDR)
Flight Management System (FMS)
Flight Simulator
Fly-by-Wire
Forward Looking Infrared (FLIR)
Garbage in, Garbage out
Ground-Proximity Warning System (GPWS)
Head-Up Display (HUD)
High Altitude Clear Air Turbulence (HICAT)
High-Lift Systems
Liquid Crystal Display (LCD)
Multifunction Displays (MFDs)
Multiple-Site Damage (MSD)
Primary Flight Display (PFD)
Sterile Operation
Stick-Shaker
Synthetic Vision System (SVS)
Thrust Reversers
Traffic Collision Avoidance System (TCAS)
VHF Datalink (VDL)
Widespread Fatigue Damage (WFD)
Wind Shear
Wind-Tunnel Testing
Wing Spoilers (Speed Brakes)

REVIEW QUESTIONS

1. Discuss some of the early developments in jet engine technology that were included in the Boeing B-47 and Dash 80 aircraft.
2. What was the purpose of pod-mounted engine installation?
3. What were some of the challenges to safety resulting from such radical airframe designs as highly swept wings, high wing loading, increased

speeds, and long-duration flights at high altitudes?

4. Describe some technological improvements in the following stopping systems:
   a. Antiskid system
   b. Fuse plugs in the wheels
   c. Wing spoilers
   d. Thrust reversers
5. What is meant by a fail-safe design?
6. List and discuss the parameters that define the age of an aircraft.
7. What are some of the technological advances that enhanced the flight handling characteristics of today's generation of aircraft?
8. Who are the three major participants in the structural safety process? Describe their individual roles.
9. What are some of the solutions to the problems of turbulence, winds, wind shear, ice and precipitation, and volcanic ash?
10. How do ice and precipitation affect airplane operation? Describe several technologies designed to address this problem.
11. List and briefly describe at least five flight deck technology changes that have made a significant contribution to improving safety.
12. What are the basic purposes of GPWS, TCAS, and EICAS?
13. What are the basic functions of the flight management system (FMS)?
14. What is computational fluid dynamics (CFD)?
15. Discuss some of the technological advances in communications, navigation, and displays including HUDs and EFBs.
16. Describe the functions of EFVS and SVS.

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CHAPTER NINE

DESIGNING AIRPORTS fOR SAFETY

LEARNING OBJECTIVES

After completing this chapter, you should be able to

- Discuss the regulatory chronology of airport certification.
- Compare and contrast the four airport certification classes.
- Discuss the airport certification process.
- Identify and differentiate between the two types of airport certifications.
- Explain what the Airport Certification Manual is and discuss its significance.
- Identify the elements of an Airport Certification Manual.
- List and explain the required elements of an Airport Emergency Plan.
- Identify the sources of safety hazards and the applicable regulations that govern the following:
  - Airport terminal buildings
  - Hangars and maintenance shops
  - Ramp operations
  - Aviation fuel handling
  - Aircraft rescue and firefighting (ARFF)
  - Deicing and anti-icing
- Describe the airport surface operational environment.
- List the individual groups involved with airport surface operations.
- Define and discuss the following terms relating to runway safety: *runway incursion*, *operational incident*, *pilot deviation*, and *vehicle/pedestrian deviation*.
- Discuss runway incursions, trends, and statistics with respect to rates and severity.
- List and discuss control strategies and initiatives that are being proposed to minimize the occurrence of runway incursions.

INTRODUCTION

Although not the case in other types of aviation, the commercial aviation operations discussed in this book all commence and terminate at airports. The design of airports and the operations that support commercial flights must all be structured around safety. A commercial *airport*, by definition, is a tract of land

(or water) that provides facilities for landing, takeoff, shelter, supply, and repair of aircraft and has a passenger terminal. This results in a diverse collection of complex operations each with its own set of safety issues. This chapter provides an overview of the certification process, the certification manual, and safety issues concerning airports. Extended discussions are conducted on some of the more hazardous operations, such as fuel handling and runway incursions. Highlights of FAA Federal Aviation Regulations Part 139 and other relevant regulations are also reviewed.

AIRPORT CERTIFICATION

The Federal Aviation Act of 1958 was broadened in 1970 to authorize the FAA Administrator to issue operating certificates to certain categories of airports serving air carrier aircraft. The 1970 Act also added a clause that barred any person from operating an airport or any air carrier from operating in an airport that did not possess a certificate if it was required or if the airport was in violation of the terms of an issued certificate.

The intent of the certification was to establish minimum safety standards for the operation of airports to ensure the safety of the flying public. To be certified by the FAA, airports are required to meet certain standards for airport design, construction, maintenance, and operations as well as firefighting and rescue equipment, runway and taxiway guidance signs, control of vehicles, management of wildlife hazards, and record keeping. The FAA works with certificated airports to help them meet these standards through periodic consultations and site inspections.

AIRPORT CERTIFICATION CLASSIFICATION

The FAA classifies U.S. airport as follows under FAR Part 139 (www.faa.gov):

- *Class I Airport*—an airport certificated to serve all of the following: scheduled operations of large air carrier aircraft, unscheduled passenger operations of large air carrier aircraft, and/or scheduled operations of small air carrier aircraft.
- *Class II Airport*—an airport certificated to serve both scheduled operations of small air carrier aircraft and unscheduled passenger operations of large air carrier aircraft. A Class II airport cannot serve scheduled large air carrier aircraft.

- *Class III Airport*—an airport certificated to serve scheduled operations of small air carrier aircraft. A Class III airport cannot serve scheduled or unscheduled large air carrier aircraft.
- *Class IV Airport*—an airport certificated to serve unscheduled passenger operations of large air carrier aircraft. A Class IV airport cannot serve scheduled large or small air carrier aircraft.
- *Joint-Use Airport*—means an airport owned by the Department of Defense, at which both military and civilian aircraft make shared use of the airfield.

In the United States, there are approximately 532 Part 139 airports as of September 2016 classified as follows (www.faa.gov):

Class I: 395 airports
Class II: 29 airports
Class III: 29 airports
Class IV: 79 airports

An airport that meets FAR Part 139 criteria is issued an *Airport Operating Certificate* (AOC). To obtain a certificate, an airport must maintain specific operational and safety standards. The FAA generally provides guidance on meeting the requirements of Part 139 certification through documents called *Advisory Circulars* (ACs). The FAA also issues annual *CertAlerts* through the Airport Safety and Operations Division of the Office of Airport Safety and Standards that serve as a quick means of providing both the public and FAA staff with important certification-related guidance.

Fully certificated airports must maintain an *Airport Certification Manual* (ACM) that details operating procedures, facilities, equipment, and other appropriate information as listed in the following section.

AIRPORT CERTIFICATION MANUAL (ACM): FAA AC No. 150/5210-22

Every certificated airport that serves air carriers is required to have an ACM in accordance with Part 139. The ACM is a working document that outlines the means and procedures used to comply with the requirements of Part 139. While each airport has its own unique features and operational requirements, its Airport Certification Manual must contain basic elements appropriate to its class, which include the following:

1. Lines of succession for airport operations responsibility.
2. Each current exemption from Part 139 issued to the airport from the requirements.
3. Any limitations imposed by the FAA Administrator.
4. A grid map or other means of identifying locations and terrain features on and around the airport that are significant to emergency operations.
5. The location of each obstruction required to be lighted or marked within the airport's area of authority.
6. A description of each movement area available for air carriers and its safety areas, and each road that serves each area.
7. Procedures during construction work for avoiding the interruption or failure of utilities serving facilities or NAVAIDS that support air carrier operations.
8. A description of the system for maintaining records.
9. A description of personnel training.
10. Procedures for maintaining the paved areas of the airport.
11. Procedures for maintaining the unpaved areas of the airport.
12. Procedures for maintaining the safety areas of the airport.
13. A plan showing the runway and taxiway identification system, including the location and inscription of signs, runway markings, and holding position markings.
14. A description of and procedures for maintaining the marking, signs, and lighting systems.
15. A snow and ice control plan.
16. A description of the facilities, equipment, personnel, and procedures for meeting the aircraft rescue and firefighting requirements.
17. A description of any approved exemption to aircraft rescue and firefighting requirements.
18. Procedures for protecting persons and property during the storing, dispensing, and handling of fuel and other hazardous substances and materials.
19. A description of and procedures for maintaining the traffic and wind direction indicators.
20. An Airport Emergency Plan (AEP).
21. Procedures for conducting the airport self-inspection program.

22. Procedures for controlling pedestrians and ground vehicles in movement areas and safety areas.
23. Procedures for obstruction removal, marking, or lighting.
24. Procedures for protection of NAVAIDS.
25. A description of public protection at the airport.
26. Procedures for wildlife hazard management.
27. Procedures for airport condition reporting.
28. Procedures for identifying, marking, and lighting construction and other unserviceable areas.
29. Any other item that the FAA Administrator finds is necessary to ensure safety in air transportation.

(*Source: FAA.gov*)

The Airport Emergency Plan is an integral part of the ACM, although it may be published and distributed separately to each user or airport tenant. The plan must be extremely detailed and provide sufficient guidance on response to all emergencies and abnormal conditions that the airport is likely to encounter. Emergencies include aircraft accidents; bomb threats; sabotage; hijackings; major fires; natural disasters such as floods, tornadoes, and earthquakes; and power failures. Emergency response plans should spell out procedures for internally coordinating with airport and firefighting personnel and the control tower. In addition, procedures should be established for coordination with external agencies such as law enforcement, rescue squads, fire departments, ambulances and emergency transportation, and hospital and medical facilities. The Airport Emergency Plan must be reviewed at least annually, and for Class I airports there must be a full-scale exercise of the plan every 3 years. (Source: FAA AC No. 150/5200-31C)

OPERATIONAL SAFETY

As mentioned earlier, airport operations are complex and diverse, with hazards and their severity varying by the type of operation. For the purposes of our discussion, airport safety issues will be discussed under the following headings:

- Airport terminal buildings
- Hangars and maintenance shops
- Ramp operations
- Specialized airport services
    - Aviation fuel handling
    - *Aircraft rescue and firefighting (ARFF)*
    - Deicing and anti-icing

AIRPORT TERMINAL BUILDINGS

These facilities are laid out to minimize passenger delays and maximize throughput of travelers from the airport terminal entry point to the aircraft. Inadequate layout and facility size leads to overcrowding, which can cause dangerous conditions that lead to injuries. Due consideration to safety should be given during the design, construction, and modification of the facilities so as to minimize hazards that cause falls and to protect people from harmful contact with machinery. Most of the design standards and requirements for building materials, fire protection, and building egress are covered by building codes (e.g., *the International Building Code*); the *National Fire Protection Association (NFPA)*; the *American National Standards Institute (ANSI)*; and other local, state, and federal agencies. For operational issues, airports should adhere to OSHA standards (which incorporate many of the standards from the above-mentioned organizations). A summary of important safety considerations for airport terminal facilities follows:

- Emergency evacuation and egress routes, signs, and other marking should conform to the Life Safety Code, NFPA 101, and OSHA regulations 29 CFR Part 1910, Subpart E, "Exit Routes, Emergency Action Plans, and Fire Prevention Plans." Some additional notes are that:
  - Exits should be well lighted and marked.
  - Panic hardware should be installed and properly working on the inside of exterior doors used for emergency exits.
  - Exits doors should be kept unobstructed and unlocked in the direction of egress.
  - Emergency evacuation plans should be posted in all buildings.
- All areas must be accessible to persons with disabilities (more information on the Americans with Disabilities Act of 1990 and this topic can be found in Advisory Circular 150/5360-14).
- All slip and trip hazards must be eliminated, and fall prevention strategies should be implemented on stairways, escalators, and moving walkways.
- Stairs, ladders, and ramps should be kept clean and free of obstacles or slippery substances and should be maintained in good condition. Both interior and exterior stairways should be sufficiently lighted so that all treads and landings are clearly visible. Prevention of falls, slips, and trips on any walking and working surface is regulated under 29 CFR Part 1910 Subpart D.
- There must be safe access to heating, ventilation, and air-conditioning

systems for maintenance to permit safe and convenient replacement of heavy equipment (e.g., pumps and motors). In this connection, safe means for maintaining luminaries and windows must be provided.

- Skylight and roof openings must be provided with protective screens to prevent individuals from falling through.
- Doors should open automatically to eliminate inconvenience to people with baggage and to the handicapped. Also, doors should open away from the person going through.
- Escalators, elevators, and moving sidewalks should comply with ANSI Standard A17.2 (Series). Speeds for moving walkways and escalators should be set at the lower limit of the acceptable range.
- Moving walkways should have emergency stop buttons at both ends, and, wherever feasible, every 50 meters apart. Attention-grabbing techniques should be installed to warn passengers that they are approaching the end of a moving walkway.
- Ticket counters should be ergonomically designed to permit safe body postures during baggage handling and data entry. Weight scales and post weigh-in baggage conveyors should be installed as close to floor level as practical to minimize lifting, and entrances to the scales should be free so as to permit baggage sliding as opposed to lifting. OSHA regulates ergonomic hazards (or any other recognized hazard that does not have a specific regulation) under the General Duty Clause listed in Section 5(a) of the OSHA Act.
- All electrical systems and power service should be installed, maintained, and inspected according to the National Electrical Code, NFPA 70. OSHA regulates electrical practices under 29 CFR Part 1910 Subpart S.
- Fire extinguishers and sprinkler systems should be installed and maintained in accordance with NFPA 10 and NFPA 13. OSHA addresses fire prevention under 29 CFR Part 1910 Subpart L.

HANGARS AND MAINTENANCE SHOPS

- Maintenance and other operational issues
  - Roofs should be inspected regularly, especially after violent storms.
  - The maximum allowable loading per square foot of floors should be prominently displayed in all storage areas to avoid damage or collapse.
  - Floors and stairways should not be waxed if it creates a slipping hazard.

- Planning and design guidance for airport terminals is included in Advisory Circular (AC) 150/5360-13 and AC 150/5360-9 for non-hub locations. Construction of hangars is covered by federal, state, and local building codes as well as many National Fire Protection Association standards. Operational issues are mostly covered by OSHA and EPA requirements. Some of the highlights include the following:
  - Walkways and working surfaces
    - Adequate aisle space and access to fire extinguishers, hoses, sprinkler control valves, and fire alarm stations should be maintained.
    - If work is performed at elevations in excess of 4 feet, the worker must be protected from falling by providing guardrails 42 inches high with an intermediate rail approximately halfway between the top rail and the standing surface. If guardrails are not feasible, an equivalent effective means of fall protection (safety harnesses, nets, etc.) must be provided. Regardless of height, if a work platform is adjacent to a hazard (e.g., dangerous equipment), then the worker must be protected from falling. Toe boards should be provided for the work platform on the open sides to prevent objects from falling on persons passing beneath or if there is moving machinery or if there is equipment with which falling material could create a hazard.
  - Electrical
    - Large metal complexes such as aircraft docks should be permanently bonded, grounded, and secured to a permanent structure such as a hangar floor. Primary sources of electric power to hangars should be approved for the location according to the National Electrical Code, NFPA 70, and aircraft hangars, NFPA 409.
    - All other electrical operational issues such as grounding, wiring, receptacles, and circuit breakers are covered by 29 CFR Part 1910 Subpart S.

COMPRESSED GAS, FLAMMABLES, AND HAZARDOUS AND TOXIC SUBSTANCES. Storing and handling of compressed gases and flammable and combustible liquids are addressed under 29 CFR 1910 Subpart H, Hazardous Chemicals. Many of these standards reference or incorporate those developed by the NFPA and the Compressed Gas Association. Toxic and hazardous substances are addressed under 29 CFR Part 1910 Subpart Z.

- 29 CFR 1910.101(b) addresses the in-facility handling, storage, and

utilization of all compressed gas cylinders. These cylinders should be secured and stored upright when not in use and should be stored in carts designed for that purpose when in use. Gas cylinders should have their caps on except when in use. Cylinders of compatible gases should be stored together, and oxygen cylinders should be stored separately from flammable gas cylinders and other flammable or combustible substances.

- General-purpose compressed air systems should not exceed 30 pounds per square inch unless specifically required (e.g., for tire inflation and special-purpose pneumatic tools). The practice of using compressed air to clean personal clothing should be avoided.
- All flammable and combustible materials (paints, hydraulic fluids, greases, solvents, cleaning agents, etc.) should be stored and used in accordance with NFPA 30. Information on the use and handling of specific materials and processes can be found in 29 CFR Part 1910 Subpart H and 29 CFR Part 1910 Subpart Z, Toxic and Hazardous Substances.
- Storage of flammables should be limited to quantities that are permitted for immediate short-duration uses in the shop areas. These chemicals should be stored in labeled cabinets designed and approved for flammable storage. Bulk storage of flammables should be in separate buildings designed for that purpose, which include design features such as explosion-proof electrical systems, spill containment, and automatic fire protection. Storage quantity requirements for shop and bulk storage can be found in 29 CFR 1910.106.
- Painting and stripping are hazardous activities that use toxic chemicals, and thus, must be performed in well-ventilated areas that are separate from other maintenance activities and are designed for that purpose (e.g., paint booths). In addition, painting and stripping generate toxic wastes that must be contained and either recycled or disposed of appropriately. Therefore, these operations are governed by both OSHA and EPA regulations.
- Miscellaneous on-site use of all chemicals is covered under OSHA's Hazard Communication Standard, 29 CFR Part 1910 Subpart 1200. This standard comprehensively addresses the issues of chemical hazard evaluation, employee hazard communications, and employee personal protective equipment and procedures.

In summary, this subpart requires the following:

- Developing and maintaining a written hazard communication program for the workplace, including lists of hazardous chemicals present on site.

- Labeling chemical containers in the workplace and those being shipped to other workplaces.
- Preparing and distributing material safety data sheets (MSDS) to employees.
- Developing and implementing employee training programs that detail the hazards of chemicals on site and what employees must do to protect themselves.

Miscellaneous upkeep of shop and hangar areas:

- The control of hazardous energy standard (29 CFR 1910.147) covers the servicing and maintenance of machines and equipment in which the unexpected energization or start-up of machines or equipment, or release of stored energy (electrical, hydraulic, pneumatic, or gravity), could cause injury to employees. This standard requires maintenance personnel, through written equipment-specific procedures, to de-energize stored energy and positively block off all potential energy sources to systems that are being worked on by using personalized locks and tags; a process known as lockout and tagout, sometimes referred to by the acronym LOTO.
- Material handling equipment such as overhead and gantry cranes that are used to move large aircraft sections are regulated under 29 CFR 1910.179. Slings, chains, and hoists used to move or lift smaller aircraft parts and sections (e.g., aircraft jacking) are regulated under 29 CFR 1910.184.
- The use of powered material handling equipment, such as fork trucks and hand trucks, and the use and maintenance of batteries used to power these and other equipment are regulated under 29 CFR 1910.178.
- Hoist units, such as those used to reach large aircraft tails, should comply with safety requirements listed under 29 CFR Part 1910 Subpart F, Powered Platforms, Manlifts, and Vehicle-Mounted Work Platforms.
- Heating and ventilation systems in hangars should be in accordance with NFPA 409 or the equivalent.
- Welding, cutting, brazing, and other hot works that have the potential to start fires are regulated under 29 CFR Part 1910 Subpart Q.
- Noise evaluation and hearing protection for processes such as riveting, sand blasting, grinding, polishing, and other noisy operations that exceed 85 decibels (time-weighted A scale for 8 hours) are regulated under 29 CFR 1910.95.
- The safe use of pedestal grinders and other grinding wheels is regulated under

29 CFR 1910.215, Abrasive Wheel Machinery.

Ramp Operations

The ramp area is generally designed for aircraft, not the vehicles that service and/or operate in the proximity of the aircraft. Most of the signs and markings are for aircraft. Figure 9-1 shows a Delta airplane during a push-back. Ground markings are also visible in the figure and are used to assist with orientation on the ramp. The figure also shows a baggage cart driver stopped to allow the aircraft movement and a so-called wing-walker ensuring that the wingtip and other aircraft areas do not contact obstructions. The ramp area sees a diverse collection of high-paced activities that involve aircraft, vehicles, and individuals working in close proximity to one another. Some of these activities include the following:

FIGURE 9-1 A busy ramp is typical of airports hosting commercial aircraft. (*Source: Authors*)

- Aircraft ground handling that may include taxiing, towing, chocking, parking, or tie-down

- Aircraft refueling
- Aircraft servicing—catering, cleaning, food service, *etc.*
- Baggage and cargo handling
- Conditioned air supply
- Power supply
- Routine checks and maintenance

Individuals involved with the above activities are exposed to several of the occupational hazards (and hence regulated by similar regulations) mentioned earlier, including:

- Cuts (from antennas, pitot tubes, static discharge wicks).
- Slips, trips, and falls (on the ground and from elevations).
- Strains and sprains (from baggage handling).
- Exposure to hazardous materials (fuel).
- Contact with moving parts (propellers) and bumps (undersurface of fuselage).
- Electrical hazards (tools, motor, generators)—electrical wiring should conform to National Electric Code, NFPA 70, for class I, Group D, Division I hazardous locations.
- Biohazards (bloodborne exposures during cleaning, covered under 29 CFR 1910.1030).
- High-pressure air and other fluid exposures from pressurized systems.
- Noise from engines and other equipment. Hearing protection is a significant health and safety issue during ramp operations.

In addition, there is a potential for significant injury from exposure to jet blast, moving aircraft, and moving vehicles. Since most of the operations take place outdoors, weather conditions (heat, cold, snow, rain, ice, and wind) can increase the risk of injury. Hazards due to aircraft refueling are discussed in the next section.

SPECIALIZED AIRPORT SERVICES

Specialized airport services are comprised of the following:

- Aviation fuel handling

- Aircraft rescue and firefighting (ARFF)
- Deicing and anti-icing

AVIATION FUEL HANDLING. Fuel handling is an important safety issue not only to the fuelers but also to other airport personnel, the traveling public, and the operation of the aircraft. Failure to adhere to safe operating procedures when fueling aircraft and/or transporting fuel from one location to another on the airport can result in major disasters. This potential for disaster is well recognized, although millions of gallons of aircraft fuel are handled each year without major incidents for the most part. The basic types of aviation fuel are aviation gasoline (avgas for general aviation piston operations), jet A or jet B (commercial jet uses) fuels, and JP series (military jet uses) fuels. Guidance on fuel handling in an airport environment is covered under 14 CFR Part 139.321(b) and the *FAA advisory circulars* in the 150 series (e.g., AC 150/5230-4A), all of which reflect NFPA standards (Aircraft Fuel Servicing, NFPA 407, 2007, and Aircraft Fueling Ramp Drainage, NFPA 415, 2008). It is also necessary that fueling operations, as shown in Figure 9-2, be conducted in accordance with procurement document specifications and all other applicable local, state, and federal regulations. Special attention must be paid to federal, state, and local hazardous materials regulations and to agency-specific fuel spill avoidance requirements. The major aviation safety concerns with fuel handling and other ramp hazards are covered in the following sections.

FIGURE 9-2 Ramp operators must exercise precautions while refueling jets because of the dangers associated with fuel. (*Source: Wikimedia Commons*)

HEALTH HAZARDS TO FUELERS. Repeated contact with aviation fuels can cause skin irritation and dermatitis. Skin area exposures to fuels should be washed immediately with soap and water. Eyewash stations should be conveniently located for immediate flushing in case the eyes or face comes into contact with fuel. Fuels such as avgas contain additives such as benzene. Hence, fuels can be toxic if inhaled or swallowed. Fuels can also affect the central nervous system by causing narcosis, which leaves an individual in a state of stupor or unconsciousness. Threshold limits for fuel vapors in the breathing zones are established by the *American Conference of Governmental Industrial Hygienists (ACGIH)* and 29 CFR 1910 Subpart Z (which reflects ACGIH standards).

FUEL CONTAMINATION. Fuel contamination is a major safety issue as it can affect the operation of the aircraft. Contamination can occur by refueling an aircraft with contaminated fuel or the wrong fuel grade or type. Fuel is considered contaminated if it contains any material other than what is called for

in the specifications. The two most common contaminants found in fuels are rust and water (free or emulsified). Other contaminants found include microbial growths, paint, metal, rubber, and lint. Commingling, or the mixing of different fuel grades and types, is also a serious issue. For example, mixing avgas with jet fuels can reduce the volatility and antiknock features of fuels needed for reciprocating engines, which can result in engine failure. This could also create deposits in turbine engines. To prevent commingling, FAA Advisory Circular No.150/5230-4 (series) requires the use of separate pumps, lines, standard couplings, and color codes for each type of fuel. Also, all fuel-dispensing systems should be clearly marked and labeled to indicate the grade and type of fuel they contain.

EXPLOSIONS AND FIRES DURING FUELING OR FUEL TRANSFER. There are three essential requirements for a fuel to burn. First, the fuel must be in its vapor form; second, it must develop the right fuel-to-air ratio with the surrounding atmosphere; and third, there must be a source of ignition to start the fire. In fuel handling, the first two conditions invariably exist, and there is very little one can do to completely eliminate these hazardous states. Hence, the primary objective during fuel handling is to control or eliminate ignition sources. Several ignition sources and their control are discussed in the following sections.

STATIC ELECTRICITY. Static charge discharge is one of the most important sources of ignition and presents a constant threat to safe fueling. When two dissimilar materials come in contact with each other, a static charge of electricity develops by the exchange of positive and negative charges across the contact surfaces. Static charges build up when fuel gets pumped through the fuel lines. The quantity of static electricity produced is directly proportional to the fuel flow rate. Also, due to their lower volatility, jet fuels are generally more susceptible to ignition from static discharges than are aviation fuels. Static electricity also gets generated when fuel is allowed to free-fall through the air, as when a tank is filled through a spout. An electrically charged atmosphere can build up charges on an aircraft, as can rain, snow, or dust blowing across the aircraft.

While completely eliminating static charge is impractical, several steps can be taken to minimize its buildup. Some of these steps are as follows:

- Follow correct *grounding* and bonding procedures, as listed in AC 00-34 (series), “Aircraft Ground Handling and Servicing.”
- Avoid pumping contaminated fuels since dirt and water particles in the fuel

will add to the static charge accumulation.

- Reduce fuel flow rates to decrease turbulence, where feasible. Reduced flow rates allow longer periods for the static charge to dissipate.
- Prevent fuel from free-falling through the air to the bottom of the tank.

SPARKS. Arcing may occur when electrical connections are made or from faulty equipment and improperly maintained ramp vehicles. To avoid sparks, the following precautions should be taken:

- Aircraft batteries should not be installed or removed, nor should battery chargers be operated during fueling operations.
- Aircraft ground power units should be located as far away as possible from the fueling points.
- Battery-powered tools as opposed to electrically powered tools should be used near aircraft during fueling.
- Aircraft radios should be shut off. Also, fueling should not be performed within 100 feet of energized airborne radar.
- Flashings used near the fueling area should be UL-approved for use in such locations.
- Workers near the fueling area should be advised against wearing footwear with metal nails or cleats or metal plates on the heels.

EXPLOSIONS AND FIRES DURING FUEL TANK REPAIR. Maintenance work on aircraft fuel cells and tanks, and on bulk fuel storage tanks presents similar inhalation and fire hazards as described above. It is extremely important that cells and tanks be drained and thoroughly vented before any maintenance work is attempted, especially hot work such as welding, brazing, and cutting. If tanks are large enough for an employee to enter and perform work, then confined-space testing, entry, and rescue procedures should be adhered to as required by 29 CFR 1910.146. Positive pressure should be employed for venting and should be undertaken with an approved blower (with non-sparking blades and an isolated non-sparking blower motor) using a grounded hose.

MISCELLANEOUS. Other issues to be considered for minimizing ignition sources include the following:

- No-smoking rules should be strictly enforced.

- Employees should not be allowed to carry matches, lighters, and other smoking paraphernalia when engaged in fueling operations.
- Welding, cutting, or other hot work should not be conducted within at least 35 feet (preferably 50 feet) of fueling. Similar distance restrictions should be maintained for open-flame lights and exposed-flame heaters.
- Fuel pits should be located at least 50 feet away from a terminal building or concourse.

HAZARDS FROM SPILLS. Fuel spills present varying degrees of safety issues depending on the size of the spill and the kind of response required. While simple flushing may be appropriate for small spills, larger spills may require the use of absorbents, adsorbents, and chemical fixants. Leaks from underground storage tanks (USTs) present a different set of safety issues. Spills and USTs are regulated by EPA (as mentioned in earlier chapters) and local and state jurisdictions. Also, depending on the response planned by the facility, OSHA regulations 29 CFR 1910.120 could apply. Some of the issues to consider in connection with fuel spills include the following:

- Leak/spill prevention
- Emergency response procedures
- Reporting and notifications
- Spill control/containment
- Cleanup procedures
- Employee training

AIRCRAFT RESCUE AND FIREFIGHTING (ARFF). Responding to aircraft crashes is a high-risk job leaving individuals exposed to a wide variety of safety hazards such as dealing with fire, smoke, chemicals, blood, other body fluids, and lifting in awkward postures. ARFF training, therefore, should include varying levels of OSHA training depending on the level of responder involvement. To develop an understanding of the safety issues involved with aircraft rescue and firefighting, a review of current ARFF procedures is necessary.

As mentioned earlier, all certificated airports must have a plan to respond to all conceivable emergencies. The Airport Emergency Plan is an integral part of the Airport Certification Manual. A major emergency that an airport has to plan for is aircraft crashes, which are handled under the aircraft rescue and firefighting plan. This plan is based on the largest aircraft that is likely to be serviced by the airport. Detailed requirements and procedures for ARFF

serviced by the airport. Detailed requirements and procedures for ARFF equipment and agents are contained in FAA regulations as follows:

- Part 139.315 (Aircraft rescue and firefighting: Index determination).
- Part 139.317 (Aircraft rescue and firefighting: Equipment and agents).
- Part 139.319 (Aircraft rescue and firefighting: Operational requirements).

Aircraft rescue services and firefighting equipment are based on an index as determined by the length of the air carrier aircraft and the frequency of departures. Figure 9-3 shows an example of the type of fire and rescue vehicle that may show up in the event of an emergency. For current information on FAA ARFF Advisory Circulars, please see the AC 150/5200 (series) of documents. For further information on airport index classification and other ARFF requirements refer to Title 14, Part 139 Subpart D (Operations).

FIGURE 9-3 ARFF fleets consist of technologically advanced vehicles for fire extinguishing efforts. (*Source: Wikimedia Commons*)

DEICING AND ANTI-ICING. Ice and snow on control, airfoil, and sensor surfaces

can have serious repercussions on the safe operation of the aircraft. Hence, when freezing or near-freezing conditions are likely to be present, the aircraft should not be allowed to takeoff before being sprayed with deicing fluid when contamination is present or anti-icing fluid when contamination may occur prior to becoming airborne. Once in the air, commercial aircraft have systems that prevent the accumulation of most types or icing, but those systems are inadequate on the ground due to several unavoidable design criteria. Figure 9-4 shows a deicing or anti-icing operation underway with spraying protective fluid on the top of a main wing.

FIGURE 9-4 Personnel deicing the wings of an aircraft prior to takeoff. This is essential since wing icing can adversely affect the aerodynamics of a plane. (*Source: Wikimedia Commons*)

To the naked eye it can be difficult to distinguish if a deicing or anti-icing operation is underway. Sometimes a deicing operation is performed first to remove contaminants and then is followed by an anti-icing operation if precipitation is still occurring that could cause future contamination. Sometimes deicing occurs without anti-icing and vice versa. Often both operations are described under the term “deicing” out of simplicity. Numerous accidents have occurred due to attempted takeoffs with contaminated surfaces. The reader should also note that such accidents can happen outside of winter. For example,

an MD-80 completing a long flight and then performing a quick-turn on the ramp in a humid environment, such as Los Angeles, can have frost form on parts of the wing since the fuel that was not used in the wings had several hours to chill while cruising at altitude. This situation may occur at outside air temperatures that are significantly above freezing and on a beautiful sunny day. That is why it is not uncommon to see deicing trucks in operation at locations such as Los Angeles, which some might find difficult to understand because the city is often associated with a modest climate.

Since this chapter is about airport safety, let us focus on the risks associated with the actual deicing/anti-icing operation. Deicing and anti-icing operations present five distinct hazards:

- Damage to the aircraft by the deicing equipment.
- Application of deicing fluid to areas where it should not be applied, such as static ports, pitot heads, angle-of-attack sensors, the engine, and other inlets.
- Hazards (inhalation and ingestion) to the deicing crew and to the environment, since deicing fluids are considered hazardous materials and are moderately toxic.
- Hazards to the crew and passengers if the cabin air intakes are not shut off during deicing.
- Falls, slips, and other safety hazards during the application process.

Deicing crews should have training as required by OSHA’s Hazard Communication standard (29 CFR 1910.1200). Also, material safety data sheets (MSDS), which list health hazards and protection information on the deicing and anti-icing fluids being used, should be made readily available. The vapors or aerosols of deicing fluids can cause nose and throat irritation, headaches, vomiting, and dizziness. For high-volume applications it is recommended that personnel be fitted with respirators in accordance with 29 CFR 1910.134. Ingestion of deicing fluids can affect the kidneys and the central nervous system. However, these fluids are so highly diluted with water that large quantities would need to be consumed to be lethal.

Application crews usually work on elevated platforms (baskets at the end of booms) and would therefore have to be adequately protected from falling through safety harnesses and guardrails. Finally, spent fluid is a regulated waste and therefore should be used, collected, and recovered/disposed of in accordance with EPA and other federal and local regulations. The FAA has recently adopted the European deicing standard called the Standardized International Aircraft

Ground Deice Program. FAA Advisory Circular 120-60 (series) is the primary FAA guidance document for the development of an air carrier's ground deicing program.

RUNWAY INCURSIONS

The prospect of two planes colliding is horrifying. It conjures an image of twisted, flaming wreckage falling from the sky. Yet such catastrophic collisions can easily occur on the ground when the safe, coordinated use of runways breaks down. The worst aviation disaster on record was, in fact, the result of two Boeing 747s colliding on a runway at Tenerife Airport in the Spanish Canary Islands. It was foggy when the accident occurred in 1977, as the captain of one of the Boeing 747s failed to obey a "hold in position" instruction from air traffic control (ATC) and started his takeoff roll before the other Boeing 747 cleared the runway. This catastrophic incident resulted in the loss of 583 lives. In the United States, the deadliest runway incursion accident occurred in August 2006 in Lexington, Kentucky, when Comair Flight 5191, a regional jet, crashed after taking off from the wrong runway, killing 49 of the 50 people on board (NTSB.gov). The reasons for these significant problems are varied and complex but can be boiled down to human error, often associated with communication and operating in a challenging and sometimes confusing environment.

Improving runway safety was on the NTSB list of "Most Wanted Transportation Safety Improvements" for nearly two decades. The FAA's report on incursion severity for the period of FY2004 to FY2007 documents a total of 1,353 runway incursions spread over nearly 250 million hours of operation. This approximates 5.4 runway incursions per million operations. Of these 1,353 incursions, 92% were minor in nature. While this is a good record by any measure, there is serious concern that an increasing number of airplanes, vehicles, and people are mistakenly coming dangerously close to each other.

With predicted increases in air traffic volume in a system that is already constrained, the number of incursions would most certainly increase. What's more, even if the incursion rates stay the same, there will be an increase in the absolute number of incursions if nothing is done about it, which of course would increase the probability of catastrophic incursions. It is for this reason that the FAA places a very high priority on controlling runway incursions. Despite the fact that pilot deviation errors result in more runway incursions than any other factor, minimizing runway incursions requires a joint effort from all groups involved in the management of the airport operations system, that is, the pilots, controllers, vehicle operators, and other ground staff.

In recent years, the FAA has joined forces with ICAO member countries and industry groups to take an integrated approach to the serious problem of runway incursions. A Global Runway Safety Symposium at ICAO in May 2011 recommended a multidisciplinary approach to improving runway safety outcomes. Terminology and definitions used have been harmonized to provide a better understanding of the problem of runway incursions.

Both ICAO and FAA have jointly defined a runway incursion as follows: "any occurrence at an aerodrome involving the incorrect presence of an aircraft, vehicle, or person on the protected area of a surface designated for the landing and takeoff of aircraft."

In order to promote global harmonization and effective data sharing, both ICAO and FAA have also established a standard classification scheme to measure the severity of runway incursions, as seen in Figure 9-5.

Category D	Category C	Category B	Category A	Accident
Incident that meets the definition of runway incursion such as incorrect presence of a single vehicle/person/aircraft on the protected area of a surface designated for the landing and takeoff of aircraft but with no immediate safety consequences.	An incident characterized by ample time and/or distance to avoid a collision.	An incident in which separation decreases and there is a significant potential for collision, which may result in a time critical corrective/evasive response to avoid a collision.	A serious incident in which a collision was narrowly avoided.	An incursion that resulted in a collision.

FIGURE 9-5 Runway incursion severity classification. (*Source: FAA*)

According to the latest FAA National Runway Safety Plan (2015–2017), the number of most serious incursions—Categories A and B—continued to fall from a total of 67 in FY2000 to just 11 in FY2013. Between FY2008 and FY2010, Category A and B events fell at a rate of 50% per year.

Airport Surface Environment

The typical airport surface environment is a complex system of markings, lighting, and signage coupled with layouts that vary by airport. Under adverse weather conditions, the complexity of the environment increases as visibility diminishes and visual cues are concealed. Cryptic signs and surface markings together with pilots new to a particular airport pose additional difficulties, as does nighttime flying where airport lights blend with background city lights.

It is within this environment that large numbers of individuals with varying levels of experience, training, and language proficiency must concentrate on performing their tasks against a backdrop of intense radio communications for coordinated actions and procedures that are needed for smooth and safe operations—all this while interfacing with large numbers of airplanes and ground vehicles of differing makes and models that are in close proximity to one another. Given the complexity and intensity of the operation, it is easy to understand why even well-trained, highly conscientious individuals remain vulnerable to error, especially when faced with unusual or unexpected situations. Runway incursions are invariably the result of human error. With expected growth in air traffic over the next several years likely to exceed planned capacity requirements, even if the incursion rate is reduced or held steady, the absolute number of these events could increase over time.

Since runway incursions result from human error, be it associated with ATC, aircrew, or airport design, it would be beneficial to review some of the jobs and tasks involved with conducting airport operations so that one can get a better understanding of which task elements have the greatest potential to cause errors. Airport ground operations are managed by air traffic controllers, pilots, and airport personnel. These groups jointly manage aircraft; coordinate vehicular traffic; and monitor and maintain conditions of runways, taxiways, aprons, signs, markings, and lighting.

Controllers serve as the hub for the entire operation. Issuing clearances, instructions, and advisories to pilots and other ground vehicle operators, controllers guide all traffic that operates on the aprons, taxiways, and runways. Controllers monitor the surface conditions together with the identity, location, and movement of aircraft and other vehicles by looking out through the tower

windows. Pilots for their part use airport layout maps, surface taxiway/runway signs, markings, and lighting that they observe from the flight deck to guide them from the runways to the gates and back. Pilots and controllers rely primarily on visual feedback to maintain situation awareness and separation. Vehicle operators manage baggage, fuel, catering, and miscellaneous ground handling functions. They are required to follow controllers' instructions to maneuver, especially if they have to cross runways. A sampling of vehicles required at most airports includes the following:

- Fuel trucks for aircraft refueling.
- FAA vehicles for monitoring and maintaining navigation equipment, radars, visibility-measuring equipment, and certain lighting systems.
- Airport authority vehicles to check for foreign objects and monitor runway conditions.
- Maintenance vehicles.
- Snowplows and mowers for maintaining runways and surrounding areas.
- Baggage, catering, and utility trucks for flight service.
- Emergency vehicles for crash and fire rescue.
- Construction vehicles for maintaining airport surfaces or new construction.

As can be seen from the preceding discussion, there is ample opportunity for human error given the significant combination of tasks, procedures, and equipment that must be coordinated to permit the operation of the system.

TYPES OF AIRPORT SURFACE EVENTS

Runway incursions are classified by type, typically falling into one of three categories as indicated below:

- *Operational Incident*—a surface event attributed to ATC action or inaction.
- *Pilot Deviation*—action of a pilot that violates any federal aviation regulation. (Example: A pilot crosses a runway without a clearance while en route to an airport gate).
- *Vehicle/Pedestrian Deviations*—any entry or movement on the movement area or safety area by a vehicle (including aircraft operated by a non-pilot or an aircraft being towed) or pedestrian that has not been authorized by ATC.

CONTROL STRATEGIES AND FUTURE INITIATIVES

The FAA's Office of Runway Safety has sponsored several initiatives to improve this critical safety area. In its document entitled National Runway Safety Plan 2015–2017, the FAA outlines several programs, which should further the progress of increasing runway safety over the next several years:

SAFETY MANAGEMENT SYSTEM (SMS) IMPLEMENTATION. In 2005, ICAO directed its member nations to establish an SMS program at all certificated international airports. The FAA has taken the following steps to implement SMS externally and internally at more than 530 airports certificated under FAR Part 139:

- The latest FAA's notice of proposed rulemaking was issued in July 2016. The FAA now proposes to require an SMS only for those airports classified as a small, medium, or large hub airport.
- FAA has issued Advisory Circular 150/5200-37 (series) to introduce SMS to U.S. airports. Runway safety will remain a top priority for FAA using the four SMS components of Safety Policy, Safety Risk Management, Safety Assurance, and Safety Promotion. Additional information on the SMS process will be provided in Chapter 12.

CURRENT TRAINING AND EDUCATIONAL OUTREACH PROGRAMS:

- Quarterly air traffic controller refresher training at every control tower.
- Pilot training and instruction during flight instructor review clinics and during flight reviews to increase situational awareness.
- Utilization of the FAA Safety Team and the AOPA Air Safety Foundation to promote educational programs including runway safety videos at both the national and regional levels. These outreach programs will train general aviation pilots in runway safety principles.
- Runway Safety Action Teams have been established to develop action plans for specific local airports.
- FAA promotion of industry association and ICAO runway safety seminars such as the Global Runway Safety Symposium in Montreal, Canada (May 2011).

TECHNOLOGY DEVELOPMENT TO CONTROL RUNWAY INCURSIONS:

- *Airport Movement Area Safety System (AMASS)* has been installed at the

nation's top 34 airports to provide an automatic visual and audio alert to controllers when the system detects potential collisions.

- *Airport Surface Detection Equipment, Model X (ASDE-X)* is being deployed at 35 of the busiest U.S. airports to provide precise surface detection automatically using a combination of radar, transponder, and ADS-B technology.
- *Runway Status Lights (RWSL)* are being deployed at 22 large airports. RWSL are red lights embedded in the pavement to signal potentially unsafe situations.
- *Final Approach Runway Occupancy Signal (FAROS)* is designed to provide a visual alert of runway status to pilots in flight by automatically flashing the Precision Approach Path Indicator (PAPI) lights whenever a runway is occupied.
- *Electronic Flight Bag (EFB)* with Moving Map Displays. Using this new technology, pilots are able to see exactly where their aircraft is on the airfield.

Local Airport Solutions As previously discussed, the FAA encourages development of runway safety initiatives at the local level to solve problems that are unique to a particular airport. In addition, participation in information sharing at the regional, national, and global levels is encouraged so that successes and lessons learned in one locale can be applied with changes, where appropriate, to other regions. Local airports and regions are encouraged to maintain and update a central information source of newly implemented corrective actions and their effectiveness in preventing runway incursions. To promote safer ground operations, the FAA offers all airports the ability to create their own Web sites on which they can post airport-specific information and advisories. Informative booklets on airport basics, operations at towered and non-towered airports, phraseology, and emergency procedures are also readily available from the FAA.

RUNWAY EXCURSIONS

Unlike the unintentional penetration of a runway's protected areas during ground operations, runway excursions are different phenomena altogether and have to do more with aircraft control during the takeoff and landing phases of flight. The public sometimes associates these events with "running out of runway" during landing, but as the case study in this chapter will illustrate, the phenomena can

also be associated with takeoffs. The FAA defines runway excursions in the National Runway Safety Plan 2015–2017 as, “a veer off or overrun from the runway surface.” Examples of factors associated with runway excursions include the following:

- Aircraft that reject their takeoff at speeds above their computed maximum for such operations, perhaps due to a detected malfunction, and which are unable to stop in the available runway.
- Aircraft that reject their takeoff at speeds below their computed maximum for such an operation, but which mistakenly do so for reasons associated with malfunctions to their systems that affect their braking ability, such as hydraulic or anti-skid failure annunciations.
- Unstable approaches that result in delayed or excessively fast touchdowns and from which aircraft are unable to stop on the remaining runway.
- Landing at wrong airports, wrong runways, or even mistakenly landing on taxiways believing that it is a runway, in which insufficient length exists on the surface to allow aircraft deceleration prior to stopping.
- Losing directional control of an aircraft during takeoff or landing, possibly due to runway contamination, such as ice; hydroplaning; or an asymmetric thrust condition, such as what is associated with the failure of an engine.
- Miscalculated aircraft performance data that indicate the aircraft has sufficient runway to takeoff or land, sometimes associated with improper data entry into automated performance calculation systems.

ASRS EXAMPLES

The airport ramp is a very busy place, as there are multiple activities simultaneously occurring to get planes in and out of the airport. The ASRS examples below show how the fast-paced environment can have an impact on safety.

RAMP SURFACES

Title: Concrete parking pad causing taxiing difficulty.

> *Three minutes after landing in Richmond, VA, while taxiing to our assigned Gate, we shut down Engine 2, and continued to single-engine taxi, per Company Policy. As we approached the gate the First Officer (Pilot Monitoring) and I (Pilot Flying) confirmed that all ground equipment was outside the footprint of the ramp area for the gate. We approached at a taxi speed of approximately 5 knots, while being directed*

by the Marshaller, with a wing walker on the left and a wing walker on the right.

At approximately 5 to 10 feet prior to reaching the parking position, the aircraft main tires met with a significant change in the ramp surface level where the ramp surface changes from asphalt to a concrete pad. In other words, there seemed to be a significant "lip" from the edge of the asphalt to the edge of the concrete parking pad used for parking aircraft. When the aircraft main tires reached this point of transition from the asphalt to the concrete at a speed of approximately 5 knots or less, the aircraft stopped its forward progress and began to move backwards, whereupon the aircraft brakes were applied, and the aircraft stopped. At this point, the aircraft was not yet at the correct parking position. The Marshaller continued to direct us to move forward and thrust was increased on Engine 1 to attempt to move forward across the "lip" between the asphalt ramp and concrete pad. With only Engine 1 operating, we were not able to move the aircraft forward to the correct parking position without using more than the maximum breakaway thrust of 40% N1. An announcement was made to the passengers and instructions given to remain seated with seat belts fastened until Engine 2 was restarted and the aircraft was properly positioned at the gate. With the aircraft stopped and the parking brake set, we signaled to the Marshaller that we were starting Engine 2.

After starting Engine 2, the Marshaller began to direct us to the proper parking position. With both engines running, maximum breakaway thrust on both engines (and possibly more) was needed to move the aircraft across the "lip" between the asphalt portion of the ramp area and the concrete parking pad to the proper parking position as directed by the Marshall[er].

The event occurred due to a taxi speed not adequate to allow the aircraft to transition from the asphalt portion of the ramp to the concrete portion of the ramp used as the parking pad. Following this event, after speaking with a Company Customer Service Representative in Richmond, it was learned that repair work to the ramp area in question had been performed on more than one occasion, due to similar events occurring with other aircraft parking at Gate. It is evident that this may be an ongoing issue and concern, at least at this particular gate in Richmond.

In addition, this flight segment to Richmond departed late due to an earlier flight we operated in arriving over one hour late. While sensing a need to get the customers to the gate after landing in Richmond, because the flight departed late and arrived in Richmond late (i.e. "rush to comply"), excessive thrust was used in an attempt to get the aircraft to the parking position and avoid any further delay.

Following this event, after careful review and consideration, I am concerned that the course of action taken by me (Pilot Flying) was not in the best interest of safety, especially with regard to the protection of Company personnel and equipment. While being directed by the Marshaller toward the parking position, and while attempting to taxi across the "lip" between the asphalt portion of the ramp and the concrete parking pad using maximum breakaway thrust (and possibly an exceedance of maximum breakaway thrust) first with one engine operating, and then with both engines operating, serious injury to ramp personnel, FOD damage to the aircraft engines, and damage to ground equipment in front and behind the aircraft, could have occurred. Thankfully, no personnel were injured, no FOD damage occurred in either engine, nor was there any damage to ground equipment in front of or behind the aircraft.

In the future, the primary suggestion to myself, or anyone else, to avoid a reoccurrence of this event, or any similar event, is as follows: When an amount of thrust equal to maximum breakaway thrust is not sufficient to move the aircraft into the proper parking position:

1. *Do not exceed maximum breakaway thrust in an attempt to reach the parking position.*
2. *Set the parking brake.*

3. *Coordinate with Operations/Ground Crew to be towed to the parking position.*
4. *If required by Company or Local Policy/Procedure, or if requested by Operations or the Ground Crew, shut engine(s) down prior to towing.*

Discussion question for the reader: If you managed the airfield where this incident occurred, what would you do to prevent a recurrence of the situation?

PESKY GROUND VEHICLES

Title: Ground vehicles failing to yield to aircraft during taxi.

LAX Ramp Tower cleared us to push back. After both engines were started and after the salute/end marshaling signal, the First Officer obtained clearance to taxi to the top of the alleyway. I observed a white van disappear behind the FO's side window. The van appeared to be on our side of the solid white line depicting the boundary of the alleyway. As I slowed the aircraft to a stop, the van disappeared and a white pickup truck following the same path stopped abeam the First Officer's side window. The FO advised Ramp Tower that we would like all of the ground equipment to move to the terminal side of the white line before proceeding with our taxi. We were stopped for about 20 minutes while one vehicle after another drove into that same spot and stopped apparently oblivious to our attempt to taxi out of the alleyway. After the [first] truck was a catering truck and then a lavatory service truck. Ramp Tower called the company with no help and finally called Airport Operations who sent a sedan with hazard lights to chase the ground vehicles out of the aircraft taxi path.

LAX [airport diagram] notes that the alleyway is extremely congested and confined. It cautions there is an "extreme jetblast hazard area" and aircraft must remain on the taxiway centerline. The wing tips are not practically visible during taxi from the 757 flight deck. There are reference points to predict the path of the aircraft structure, and some of the vehicles appeared low enough and some appeared far enough to avoid collision. However, with at least half a dozen ground vehicles of all different sizes driving and parking fully on our side of the solid white boundary lines there was no way to determine with certainty that ground collision could be avoided or that the drivers were assuring that. So, I did not move the aircraft until all of these vehicles were on the terminal side of the white line. In that 20 minutes numerous aircraft were delayed both inbound and outbound. The drivers and ground employees on foot all seemed oblivious and most never even looked toward our aircraft. They all appeared preoccupied with their own duties.

Discussion question for the reader: If you were a safety manager for the airline that experienced this incident, what different actions would you take to prevent a recurrence of the situation?

RUNWAY INCURSION

Title: Air traffic controller mentions how airport design led to a runway incursion.

It may help to refer to Figure 9-6 and trace what occurred with a pencil when reading about this event. This incident occurred at Los Angeles International Airport in California. The expression “rolling out” is used to describe a decelerating aircraft after landing touchdown.

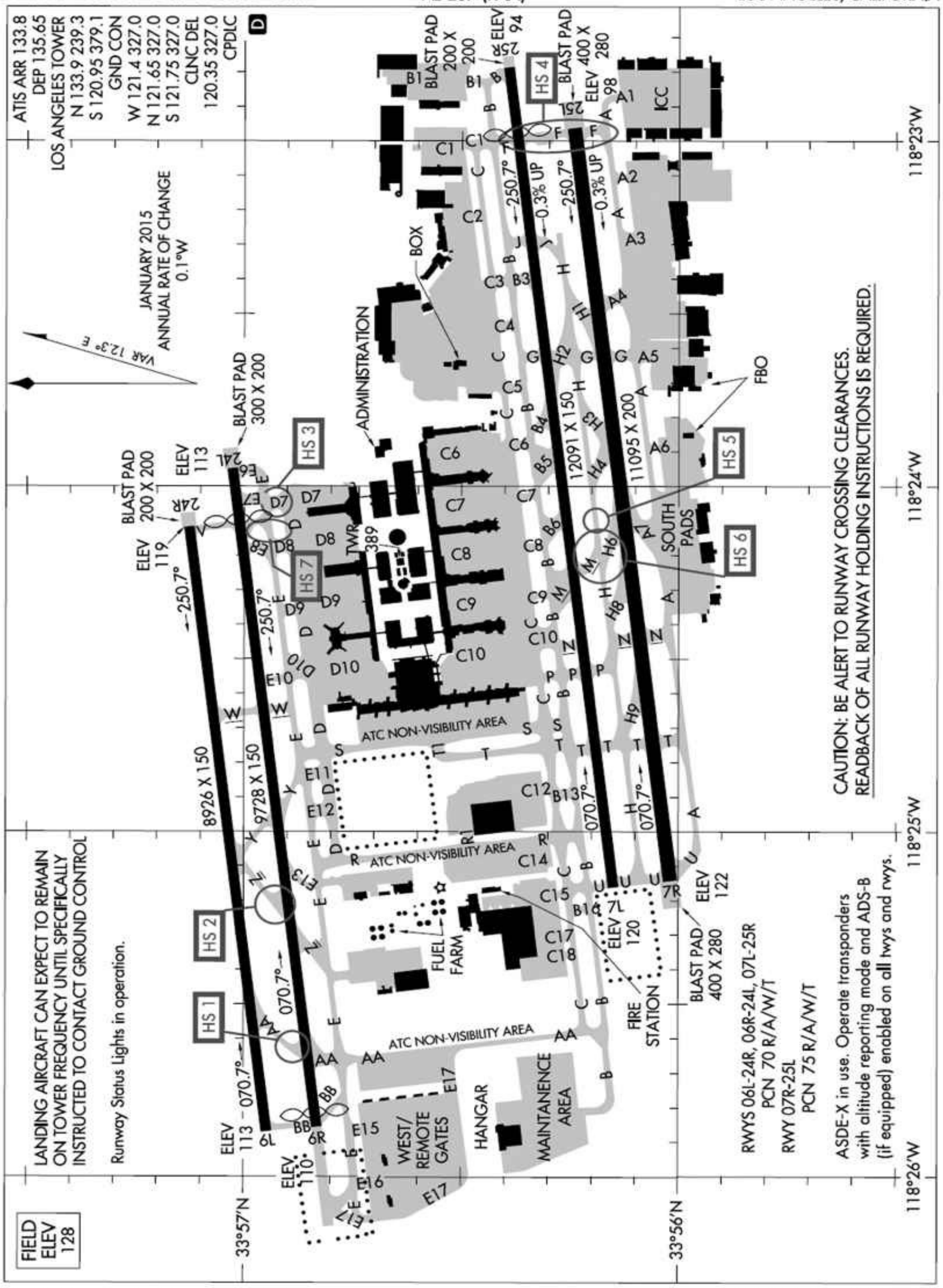
16203

AIRPORT DIAGRAM

AL-237 (FAA)

LOS ANGELES INTL (LAX)
LOS ANGELES, CALIFORNIA

SW-3, 21 JUL 2016 to 18 AUG 2016



SW-3, 21 JUL 2016 to 18 AUG 2016

AIRPORT DIAGRAM
16203

LOS ANGELES INTL (LAX)
LOS ANGELES, CALIFORNIA

FIGURE 9-6 LAX Airport diagram. (*Source: FAA*)

Narrative from air traffic controller:

I cleared Aircraft Y for takeoff on Runway 24L. Aircraft X was rolling out on Runway 24R. I took care of other things, and next thing I observed was Aircraft X was about to cross the runway while Aircraft Y was rolling one third down the runway. I yelled out "Aircraft X stop" "Aircraft X hold" then I instructed Aircraft Y to abort and cancel take off clearance. I did not cross Aircraft X, I had not expected Aircraft X to cross the runway. I expected all aircraft to hold short of the parallel runway, since there is enough space to clear the runway they just landed. Aircraft Y had to sit on the runway for about 10 minutes to check his aircraft (with help of rescue department) and taxied off the runway on his own. We need the center taxiway between Runway 24L and Runway 24R. Better educate foreign pilots to what they can and cannot do after landing.

Narrative from the departing aircraft that had to abort takeoff:

Cleared for takeoff 24L E8 shortened. As we taxied onto runway, an aircraft was rolling out on 24R. We began the takeoff roll as the aircraft was exiting onto AA. After 80 kt callout the CA questioned whether the aircraft was stopping short of 24L. We both noted that the aircraft was not stopping and the Captain called to abort the takeoff at approximately 110 kts. Immediately thereafter, tower told the crossing aircraft to "stop, stop" and called for us to abort the takeoff. The traffic had not received a clearance to cross 24L but failed to hold short of the runway. After the rejected takeoff, we remained on the runway until ARFF inspected [us] for damage. No damage noted. Returned to gate for further inspection by maintenance.

Discussion questions for the reader: Why would the presence of a center taxiway between Runway 24L and 24R reduce the chances of a runway incursion? What type of damage would ARFF search for on an aircraft after a high-speed rejected takeoff?

CASE STUDY: PSA AIRLINES FLIGHT 2495

As has been shown throughout this book, the safety value chain that protects commercial aviation against accidents and serious incidents is long and has been developed over a century of effort. It extends from the design of aircraft and airports all the way to the training of frontline personnel, such as air traffic controllers and pilots. The elements of the safety value chain work well together, and sometimes one protection will kick in when another one fails. The case study contained in this section is a perfect example.

PSA Airlines Flight 2495 illustrates how the conscientious actions that airports take to improve safety can truly be lifesavers when safety breaks down in other areas. On January 19, 2010, a PSA Airlines Bombardier CRJ 200 jet was scheduled to depart from Yeager Airport in Charleston, West Virginia for Charlotte, North Carolina. Everything leading up to the takeoff on Runway 23

seemed normal. However, when the pilots reached the 80 knot callout, the captain realized that the flaps were not configured properly on the plane. He tried to correct the settings of the flaps, but this prompted an airplane warning. As a result, the captain decided to abort the takeoff.

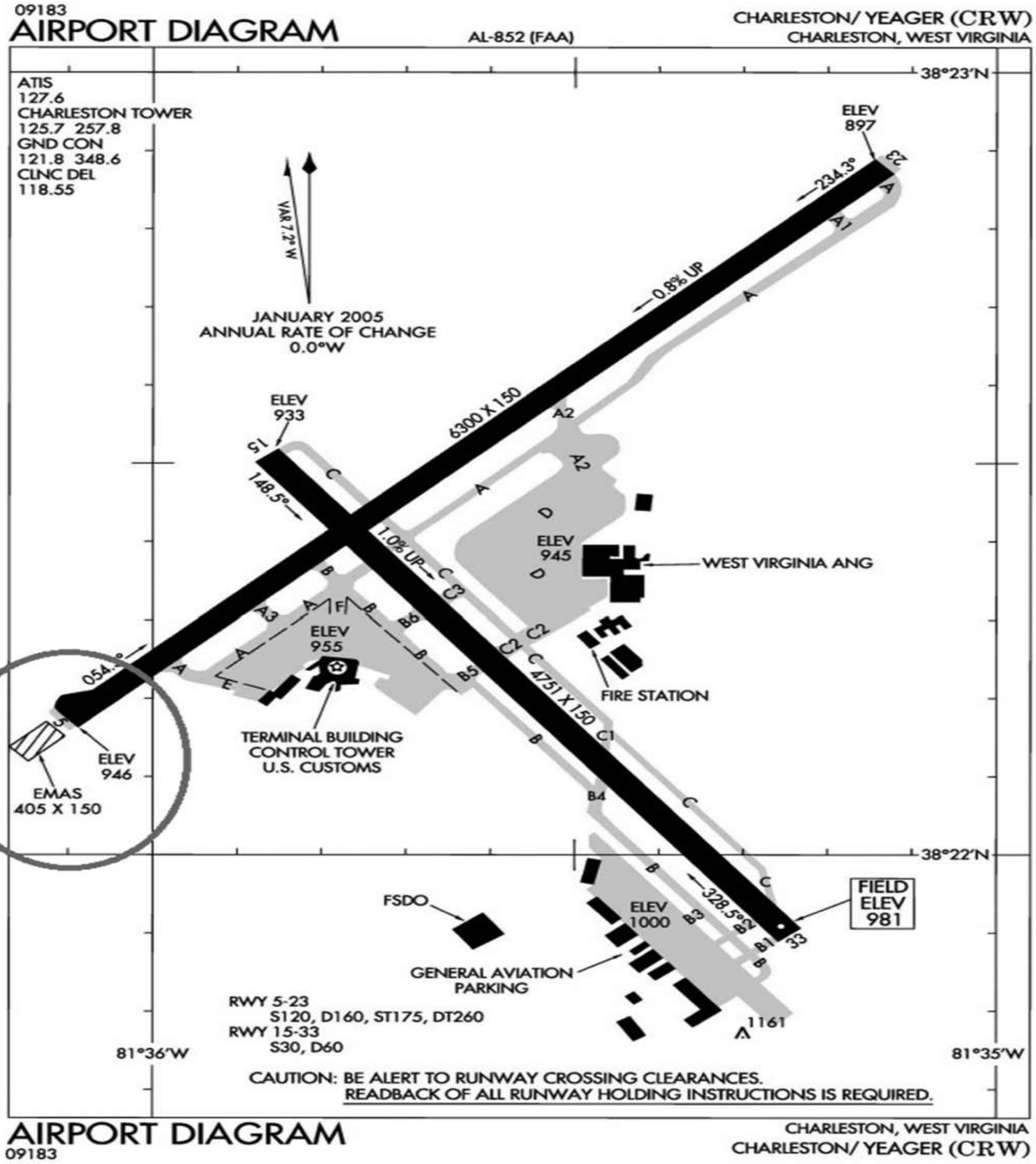
The plane was unable to stop within the runway confines and was forcibly stopped 130 feet into the 455-foot-long *Engineered Materials Arrestor System (EMAS)*. EMAS is a safety measure used in locations where there is not enough space to have a standard 1,000 foot overrun for aircraft. It is made of crushable concrete that collapses under the weight of the plane, thus stopping the aircraft's motion to prevent a crash or running off the runway. Figure 9-7 shows the PSA Airlines plane shortly after being stopped by the EMAS area at Yeager Airport.

FIGURE 9-7 Concrete blocks from the EMAS crushed under the weight of the PSA Airlines plane. (*Source: NTSB*)

All 34 passengers left the accident uninjured, and despite the appearance of the jet in Figure 9-7, there was only minor damage to the plane's flaps, landing gear, and landing gear doors. However, had it not been for the EMAS, the severity of the accident would have been much worse, probably even fatal. Having the EMAS in place offered the protection that the airplane needed against the runway overrun.

What makes this accident unique though is that Yeager Airport is built on the top of a cleared mountain. When the airport was planning an airport runway

extension project to comply with new FAA regulations, they were faced with a particular challenge. There was not enough room to extend the runway the required distance since there was a steep slope that consisted of loose sediments rock. As a result, the Central West Virginia Regional Airport Authority had to make special considerations to ensure that aircraft had a big enough safety area. Thus, the Airport decided that they needed to construct an EMAS. Prior to the installment of the EMAS in 2007, the runway safety area was only about 120 feet long. Had this still been the case, the PSA Airlines plane would have endured a different fate. Figure 9-8 shows an airport diagram for Charleston and a close-up of a part of the diagram depicting the location of the EMAS on the departure end of Runway 23.


09183
AIRPORT DIAGRAM
AL-852 (FAA)
CHARLESTON/ YEAGER (CRW)
CHARLESTON, WEST VIRGINIA
38°23′N
ATIS
127.6
CHARLESTON TOWER
125.7 257.8
GND CON
121.8 348.6
CLNC DEL
118.55
VAR 7.2°W
JANUARY 2005
ANNUAL RATE OF CHANGE
0.0°W
ELEV
897
234.3°
0.8% UP
6300 X 150
ELEV
933
148.5°
1.0% UP
ELEV
945
WEST VIRGINIA ANG
ELEV
955
FIRE STATION
4751 X 150
054.3°
TERMINAL BUILDING
CONTROL TOWER
U.S. CUSTOMS
ELEV
946
EMAS
405 X 150
NE-4, 14 JAN 2010 to 11 FEB 2010
38°22′N
FSDO
ELEV
1000
328.5°
FIELD
ELEV
981
GENERAL AVIATION
PARKING
RWY 5-23
S120, D160, ST175, DT260
RWY 15-33
S30, D60
1161
81°36′W
81°35′W
CAUTION: BE ALERT TO RUNWAY CROSSING CLEARANCES.
READBACK OF ALL RUNWAY HOLDING INSTRUCTIONS IS REQUIRED.
AIRPORT DIAGRAM
09183
CHARLESTON, WEST VIRGINIA
CHARLESTON/ YEAGER (CRW)

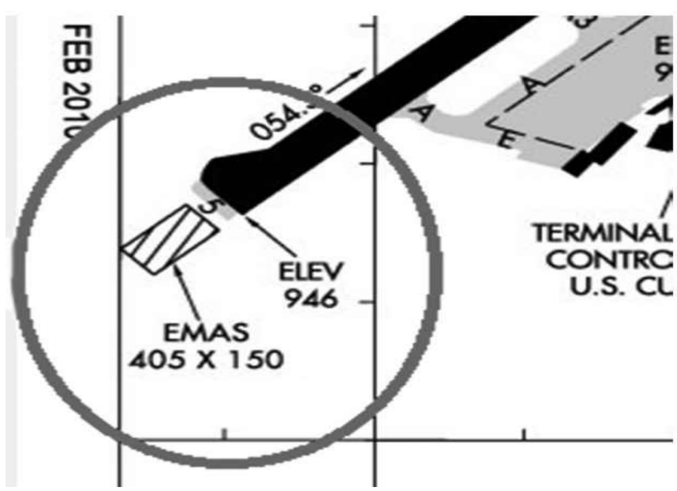

FEB 2010
054.
ELEV
946
EMAS
405 X 150

FIGURE 9-8 Close-up of what EMAS looks like on an Airport Diagram. (*Source: FAA*)

This accident highlights the importance of addressing safety risks in a complex environment. These tasks require careful considerations by professionals in the industry. As we can see with the case study, the airport was aware of the implications involved with a runway that ended right before a steep drop-off. Their effort to install an EMAS shows how they proactively turned this unsafe condition into a safe environment. Even though at the time of the accident, one 2-foot-thick, 4-by-4 foot block used in the EMAS system cost around $1,000 each, it was well worth the repair costs when you consider everyone left the accident uninjured.

CONCLUSIONS

As this chapter has illustrated, there are diverse and complex activities happening simultaneously at any airport open to commercial aviation operations. Airports involve everything both inside the airport building and on the ramp, extending out to the runways and even the areas adjacent to the airport when considering wildlife hazards. Due to this vast purview, airports must be designed and operated with several lines of defenses for safety. All of them together add greatly to the safety value chain for commercial operations.

Airport certification, as outlined in FAR Part 139, entails achieving an Airport Operating Certificate (AOC) and then being subject to periodic and occasional no-notice inspections by the FAA. Fully certificated airports must maintain an Airport Certification Manual (ACM) that stipulates, among many requirements, having an updated *Airport Emergency Plan*. The plan must be reviewed at least annually, and for Class I airports there must be a full-scale exercise of the plan every 3 years.

Detailed procedures must be created and followed to manage risks associated with the varied operations found at airports, ranging from ARFF response capabilities to the storing and handling of flammable and combustible liquids. Fuel safety is a key responsibility of airports, both from the perspective of airport employees and the commercial operations that they service. Fuels can affect the central nervous system of ground personnel by causing narcosis through exposure. As for aircraft, in much the same way that blood poisoning can cause a human to die, a perfectly functioning engine can be rendered completely unusable, sometimes in mid-flight, due to fuel contamination.

Civil aviation's worst disaster was at Tenerife in 1977 due to a runway

incursion, but thankfully incursions are rare, and incursions leading to collisions that result in deaths are even more infrequent. Numerous initiatives have been established to mitigate the risk of runway incursions and, of more recent attention, runway excursions.

The case study of PSA Airlines Flight 2495 illustrates how one safety system can make up for a deficiency in another part of aviation operations. Regulatory guidance, such as contained in FAA FAR Part 139, is indeed critical to the aviation safety professional and sets the standard for modern commercial airport safety systems.

KEY TERMS

Aircraft Rescue and Firefighting (ARFF)
Airport
Airport Certification Manual
Airport Emergency Plan
Airport Operating Certificate
Airport Surface Detection Equipment, Model X (ASDE-X) Airport Movement Area Safety System (AMASS)
American Conference of Governmental Industrial Hygienists (ACGIH)
American National Standards Institute (ANSI)
CertAlerts
Electronic Flight Bag (EFB)
Engineered Materials Arrestor System (EMAS)
FAA Advisory Circulars
Final Approach Runway Occupancy Signal (FAROS)
Grounding
National Fire Protection Association (NFPA)
Operational Incident
Pilot Deviation
Runway Incursion
Runway Status Lights (RWSL)
Vehicle/Pedestrian Deviation

REVIEW QUESTIONS

1. Which act was responsible for initiating the airport certification process and

what were its salient features?

2. What FAA FAR part number regulates airport certification? What are its highlights, and when was it first promulgated?
3. Discuss the highlights of the airport certification process and their significance.
4. What are the four classes of airport certifications and what are their differences?
5. What is the Airport Certification Manual and why is it so significant?
6. List at least five elements required in the Airport Certification Manual.
7. List and explain the required elements of an Airport Emergency Plan.
8. List five safety hazards associated with each of the following:
   - *a*. Airport terminal buildings
   - *b*. Hangars and maintenance shops
   - *c*. Ramp operations
   - *d*. Aviation fuel handling
   - *e*. Aircraft rescue and firefighting (ARFF)
   - *f*. Deicing and Anti-icing
9. What is a runway incursion?
10. List and explain the different categories of runway incursions.
11. Differentiate between runway excursions and runway incursions.
12. List individual groups together with their functions and the equipment they use for airport surface operations.
13. Explain why aircraft deicing may be required even in temperate climates such as in Los Angeles.

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http://www.faa.gov/airports/runway_safety/news/runway_incursions/

FAA Runway Safety Statistics:
http://www.faa.gov/airports/runway_safety/statistics/

OSHA Occupational Safety & Health Standards:
https://www.osha.gov/pls/oshaweb/owastand.display_standard_group?p_toc_level=1&p_part_number=1910

PSA Flight 2495 NTSB accident report:
http://www.ntsb.gov/_layouts/ntsb.aviation/brief2.aspx?ev_id=20100121X82958&ntsbno=DCA10IA022&akey=1

Sample Airport Certification Manual: Fort Lauderdale-Hollywood International:
http://www.broward.org/Airport/PilotInfo/Documents/Airportcertificationmar

CHAPTER TEN

AIR TRAFFIC SAFETY SYSTEMS

LEARNING OBJECTIVES

After completing this chapter, you should be able to

- Describe the mission of the FAA ATC and discuss major milestones of ATC history.
- Explain the basic components of the ATC system and ATC services available.
- Discuss the advantages of GPS and satellite-based navigation.
- Explain the purpose of the WAAS GPS augmentation systems.
- Give examples of recent operational planning improvement programs.
- Describe the general features of the NextGen Air Transportation System.
- Discuss recent FAR Part 107 regulations regarding Unmanned Aircraft Systems.

INTRODUCTION

While some of the previous few chapters in this book focused on how aircraft and airports are designed for safety, once commercial flights become airborne they navigate through what is often highly complex airspace and rely on an intricate air traffic system and human controllers for separation and sequencing. We have come a long way since pilots used to navigate by light from signal fires and land on runways at night using the illumination of headlights from cars. However, we still have a long way to go to efficiently accommodate the expected growth in air traffic with NextGen and Unmanned Aircraft Systems under constant development.

According to the FAA’s Air Traffic by the Numbers Web site (FAA.gov, 2016), there are 7,000 aircraft in the sky over the United States at any given time, resulting in 23,911 commercial flights that fly over 2.2 million passengers each day, all of which are directed by 14,000 air traffic controllers. The mission of the Air Traffic Control (ATC) system is to promote the safe, orderly, and expeditious flow of aircraft through the nation’s airspace. Today’s National Airspace System (NAS) has evolved over several decades into a developed

Airspace System (NAS) has evolved over several decades into a developed infrastructure requiring thousands of employees and billions of taxpayer dollars to administer.

Once a commercial airliner is airborne and into the airspace, crews constantly assess factors such as aircraft weight, fuel burn, winds aloft, cloud buildups, and turbulence in order to optimize their route and altitude. This results in frequent requests to ATC for changes which must be balanced against potential conflicts from other traffic in the immediate airspace. Often the results are of short duration, such as pilots desiring to deviate laterally to avoid a cloud buildup that may contain severe turbulence and then returning to the pre-agreed flight path once past the buildup. In other cases, the requested deviations may be significant, such as a descent to a lower altitude due to the need to operate anti-ice systems that reduce the available thrust to engines and make maintaining the current altitude untenable.

To manage the airspace and its traffic, modern air traffic controllers rely heavily and increasingly on new Next Generation (NextGen) ATC technologies, as shown in Figure 10-1. These advancements are increasing with major reliance on the *Global Positioning System (GPS)* navigational tools available. It is anticipated that the role of modern ATC professionals will continuously evolve as automation increases, much in the way that the role of the aviator was shown to be evolving in Chapter 4 of this book. A short history of the U.S. ATC system is helpful to understand its current state. Here we examine the history that has brought us the ATC system of today, some of the basic components of the system, recent improvements, and current efforts to take ATC into the future.

FIGURE 10-1 Air traffic controller using NextGen technology. (*Source: FAA*)

MAJOR MILESTONES OF ATC HISTORY

- *June 1956*. Midair collision over the Grand Canyon in Arizona, killing all 128 occupants of the two airplanes, a TWA Super Constellation and a United Air Lines DC-7. The accident happened in clear weather under *visual flight rules (VFR)* in uncontrolled airspace. Such sightseeing detours over the Grand Canyon were a common practice at the time. The accident highlighted that much of the airspace in the United States was uncontrolled without radar above 20,000 feet. It also spawned the overhaul of ATC operations, introducing modern radar systems, requirement of the flight data recorder in airplanes, and the development of the FAA.
- *December 1960*. The FAA was only 2 years old when another disastrous midair collision occurred over New York City. A TWA Super Constellation and a United Air Lines DC-8, both in a holding pattern under *instrument flight rules (IFR)*, collided killing all aboard. The United Air Lines aircraft had navigational problems and excessive speed, which could not be detected by the New York ATC towers that lacked proper surveillance radar equipment. As a result of the accident, there were equipment upgrades and a new

regulation mandating the limit of 250 knots airspeed when within 30 nautical miles of the airport and below 10,000 feet altitude.

- *August 1981*. Over 12,000 U.S. air traffic controllers went on strike over labor conditions and were fired by the FAA. It took almost 10 years before overall ATC staffing levels returned to normal.
- *January 1982*. The FAA released the first NAS Plan, a comprehensive 20-year blueprint to modernize ATC and air navigation systems in the United States.
- *April 2000*. Creation of the FAA Air Traffic Organization (ATO), a performance-based department focusing on efficient operation of the U.S. ATC system.
- *December 2003*. Next Generation Air Transportation System (NextGen) concept was authorized, a new, ambitious, multiagency effort to develop a modern air transportation system for the 21st century. This system faces significant challenges changing ATC from a radar-based to a satellite-based navigation and communication system.
- *Today*. NextGen development continues based on GPS and computer science technology. The advent of *Unmanned Aircraft Systems (UAS)*, aka "Drones," is creating a paradigm shift in ATC challenges.

The following section will discuss the fundamental components of the U.S. ATC system. A detailed discussion of this subject would require many chapters and, therefore, is outside the scope of this textbook. Since this area is changing rapidly, we recommend readers to consult the latest FAA and ICAO Web sites for more information.

BASIC COMPONENTS OF THE ATC SYSTEM

AIRSPACE CLASSIFICATION

In the United States, the FAA has designated four categories of airspace as follows:

- *Positive controlled airspace*. These are areas in which the FAA is responsible for separation of all aircraft, whether under VFR, see and avoid, or IFR. Examples of positive control areas are high-density airports and very high altitude flights above 18,000 feet mean sea level.
- *Controlled airspace*. Areas in which ATC separates IFR traffic, but VFR

pilots provide their own separation, weather permitting.

- *Uncontrolled airspace*. The pilots themselves provide all aircraft separation; ATC services are not provided by the FAA.
- *Special use airspace*. Areas where air traffic may be prohibited or restricted with special rules such as the airspace around the White House in Washington, D.C.

Airspace classifications and communication requirements are taught in basic flight training, which are beyond the scope of this textbook.

ATC Services

The basic communication and *Navigational Aids (NAVAIDS)* to aviation have changed little since the 1970s. Air traffic controllers operate primarily from three types of facilities. These basic ATC facilities are as follows:

- *Airport traffic control towers (ATCTs)*
- *Terminal radar approach control (TRACON)* facilities
- *Air route traffic control centers (ARTCCs)*

Some of the basic NAVAIDS and radar surveillance equipment used in this system are the following:

- *VHF Omni-directional Range (VOR)* and Distance Measuring Equipment (DME) stations which transmit signals along “airways,” highways in the sky, to route air traffic.
- *Instrument Landing System (ILS)*, which is a precision approach and landing aid that normally consists of a localizer, a glide slope, marker beacon, and an approach light system.
- *Airport Surveillance Radar (ASR)*, used in conjunction with a transponder radar beacon device, is an approach control radar system used to separate aircraft within the immediate vicinity of an airport; it normally has a maximum range of 60 nautical miles.

Performance-Based Navigation (PBN)

The arrival of GPS navigation tools has caused a major restructuring of ATC procedures. The FAA has recently announced its strategic goal to make PBN the

nation's primary means of navigation in the next 15 years. An in-depth discussion of PBN is beyond the scope of this textbook, so we will only discuss the highlights. In general the area of *performance-based navigation (PBN)* can be divided into two major sub areas:

1. *Area navigation (RNAV)* is a term describing different technologies that enable aircraft navigation on any desired course within the coverage of specific navigation signals. RNAV may consist of station-to-station navigation, or it may be between random waypoints offset from published routes depending upon the type of equipment used. Basically, RNAV will develop in the coming years as a GPS-dependent system, independent of the many VOR/DME navigational aids that will slowly be phased out as part of the NextGen FAA modernization program.
2. *Required navigation performance (RNP)* is a type of PBN that allows an aircraft to fly a specific path between two 3D-defined points in space. Area navigation (RNAV) and RNP systems are fundamentally similar, the key difference between them is the requirement for RNP onboard performance monitoring while flying curved approach paths to an airport. This navigational program is growing as airports and aircraft are configured for this type of precision approach.

GPS Enhancements

For many years, the U.S. aviation navigation system was composed of ground-based systems whose signals were used by aircraft avionics for en route navigation and landing guidance. Despite the large number of ground systems, navigation signals did not cover all airports and airspace. Over the next several years, the aviation navigation system is expected to greatly increase its use of GPS satellites to provide navigation signal coverage throughout the NAS.

Global Positioning System is a space-based positioning, velocity and time system, developed and operated by the U.S. Department of Defense and composed of space, control, and user segments. The space segment is composed of 21 satellites (plus three operational spares) in six orbital planes. The control segment consists of five monitor stations, three ground antennas, and a master control station. The user segment consists of antennas and receiver-processors that provide positioning, velocity, and precise timing to the user.

Reliance on ground-based navigation aids will decline as satellite navigation provides equivalent or better levels of service. A transition to satellite navigation significantly expands navigation and landing capabilities, improving safety and

efficient use of airspace. In addition, it will reduce the FAA's need to replace many aging ground systems, decrease the amount of avionics required to be carried in aircraft, and simplify navigation and landing procedures.

WIDE AREA AUGMENTATION SYSTEM

Wide Area Augmentation System (WAAS) is an extremely accurate navigation aid developed for civil aviation to augment the Global Positioning System. Before WAAS, the U.S. National Airspace System (NAS) did not have the potential to provide horizontal and vertical navigation for approach operations for all users at all locations. With WAAS, this capability is a reality. WAAS provides service for all classes of aircraft in all phases of flight including en route navigation, airport departures, and airport arrivals. This includes vertically guided landing approaches in instrument meteorological conditions at all qualified locations throughout the NAS.

ADVANTAGES OF SATELLITE-BASED NAVIGATION

Satellite-based navigation provides significant operational and safety benefits over past methods that relied on ground-based navigation aids. The new mode of navigation meets the needs of growing operations because pilots will be able to navigate virtually anywhere in the NAS, including to airports that currently lack ground navigation and landing signal coverage. Satellite-based navigation will support PBN direct routes. With satellite navigation, the number of published precision approaches has also greatly increased so that in addition to actually finding airports pilots can also successfully land there during inclement weather conditions. In addition, combining GPS with flight deck electronic terrain maps and ground-proximity warning systems can help pilots reduce flight profiles that expose them to controlled flight into terrain (CFIT).

Satellite-based navigation also decreases the number of ground-based navigation systems, thereby reducing infrastructure costs. For a precision approach today, each runway end needs a dedicated ILS. GPS/WAAS can provide the precision approach guidance for most of the runways in the NAS using RNAV and RNP procedures which are quickly expanding across the country.

TERMINAL AUTOMATION MODERNIZATION AND REPLACEMENT (TAMR)

The FAA's *terminal automation modernization and replacement (TAMR)*

program is upgrading ATC systems at terminal radar approach control (TRACON) facilities across the national air space (NAS) with the *Standard Terminal Automation Replacement System (STARS)* platform. TAMR will combine and upgrade ATC technologies to the STARS which is a single, state-of-the-art platform that will be installed at TRACONS and control towers. When fully operational, the STARS system will perform as follows:

- Maintain safety while increasing cost-effectiveness at terminal facilities across the NAS.
- Provide advanced functionalities for controllers, such as state-of-the-art flat-panel LED display and the ability to save controller workstation preferences.
- Offer maintenance improvements to keep equipment up and running.

Terminal automation systems receive surveillance data and aircraft flight plan information. Controllers at radar control facilities use these systems to manage air traffic immediately around major airports, and technicians maintain these systems at facilities. These systems enable controllers to provide the following ATC services that are critical to the safety of the national airspace:

- Separating and sequencing of aircraft
- Conflict and terrain avoidance alerts
- Weather advisories
- Radar vectoring for departing and arriving traffic

UPDATE ON FAA NEXTGEN BACKBONE PROGRAMS

Through its NextGen program, the FAA has taken major steps to enhance safety and improve efficiency in our nation's airspace. NextGen is a comprehensive modernization of state-of-the-art technologies and procedures that, in short, enable aircraft to move from Point A to Point B more efficiently and directly than ever before. This is truly a "work in progress," so for the latest information on FAA NextGen programs, the reader is urged to visit the FAA Web site.

The major backbone programs of NextGen include the following:

- *Automatic Dependent Surveillance—Broadcast (ADS-B)* is FAA's satellite-based successor to radar. ADS-B makes use of GPS technology to determine and share precise aircraft location information and streams additional flight information to the cockpits of properly equipped aircraft. The FAA has set a

goal that ADS-B will be fully operational by the year 2020. U.S. airlines are on track to meet this goal; however, the general aviation industry is struggling to meet this deadline date.

- *Collaborative Air Traffic Management Technologies (CATMT)* is a suite of enhancements to the decision-support and data-sharing tools used by air traffic management personnel. These enhancements will enable a more collaborative environment among controllers and operators, improving efficiency in the National Airspace System.
- *Data Communications (Data Comm)* will enable controllers to send digital instructions and clearances to pilots rather than relying solely on voice communications. Precise clearance messages from ATC that appear on a cockpit display can also interact with an aircraft's Flight Management Systems (FMS) computer. As of this publication, FAA control towers in over 50 locations have installed Data Comm equipment. In the near future Data Comm will supplant voice communications as the primary means of communication between controllers and flight crews.
- *National Airspace System Voice System (NVS)* will supplant FAA's aging analog voice communication system with state-of-the-art digital technology. NVS will standardize the voice communication infrastructure among FAA facilities, and provide greater flexibility to the ATC system.
- *System Wide Information Management (SWIM)* is the network backbone structure that will carry NextGen digital information. SWIM will enable cost-effective, real-time data exchange and sharing among users of the National Airspace System.
- *NextGen Weather* will help reduce weather impacts by producing and delivering tailored aviation weather products via SWIM, helping controllers and operators develop reliable flight plans, make better decisions, and improve on-time performance. NextGen Weather is accomplished through collaboration between FAA, NOAA, and NASA. The efficient handling of new weather products will greatly improve *traffic flow management (TFM)* throughout the National Airspace System. *Terminal Flight Data Manager (TFDM)* modernizes ATC tower equipment and processes. Using SWIM capabilities, TFDM will share real-time data among controllers, aircraft operators, and airports so they can better stage arrivals and departures for greater efficiency on the airport surface. The FAA currently projects that TFDM processes will roll out in 2019.

Airport Surface Detection Equipment, Model X (ASDE-X)

As frequently noted by the FAA and NTSB, the potential for runway incursions and collisions on taxiways increases each year. That is due to the continuing increase in air traffic and the associated increased frequency of aircraft operating in close proximity to each other on airport surfaces. To combat this risk, the FAA has deployed *Airport Surface Detection Equipment, Model X (ASDE-X)* at major U.S. airports. This system allows controllers to detect potential runway conflicts by providing detailed coverage of movement from surface radar, ADS-B sensors aboard aircraft, and aircraft transponders, among other sources. This technology is especially useful for controllers at night or in weather conditions of poor visibility where airport traffic is not easy to spot visually.

Departures and Arrivals

Resolving congestion at the busiest U.S. airports requires a combination of modern technology and additional runways. As depicted in Figure 10-2, engineers and technicians are testing airborne spacing for terminal arrival routes. The FAA is working with airport operators to plan and develop new runways to accommodate increased aircraft operations and use new technologies, while meeting environmental requirements.

FIGURE 10-2 Personnel use a NextGen airborne testbed to assess potential arrival routes. (*Source: NASA*)

Arriving and departing aircraft are sequenced in and out of the airport by air traffic controllers at the TRACON facilities. Maintaining a steady flow of aircraft, particularly during peak periods, can be improved by providing controllers with tools for sequencing and spacing aircraft more precisely so that more can fit into any given amount of airspace. The objective is to reduce variability in services and optimize use of airspace and available runways.

En Route and Oceanic Operations

The evolution toward a NextGen environment requires significant improvements in en route and oceanic computer systems and controller decision support tools. The aging automation infrastructure must be replaced before new applications and improved services can be provided.

Currently, en route and oceanic facilities are co-located but do not share common systems, primarily because of the lack of surveillance and direct communications services over large portions of the oceans on Earth. The

addition of oceanic surveillance and real-time direct communications will enable oceanic services to gradually become comparable with en route services, and oceanic and en route systems will evolve to a common hardware and software environment. Within both the Atlantic and Pacific airspaces, FAA controllers monitor aircraft position using *Advanced Technologies and Ocean Procedures (ATOPs)* equipment.

In the domestic airspace, aircraft are monitored by radar and typically follow the fixed route structure of airways, which prevents pilots from flying the most direct route or taking advantage of favorable winds. In oceanic airspace, aircraft follow “tracks” that are aligned each day with prevailing winds. The frequent lack of radar surveillance and direct controller–pilot communications often requires oceanic separation standards to be 20 times greater than those in domestic airspace. The large separations limit the number of available tracks. Therefore, some flights are assigned a less than optimum altitude in order to still transit the airspace without undue delay, and there is insufficient opportunity to adjust altitudes to conserve fuel.

Additional tracks and access to optimum altitudes would reduce fuel consumption and costs substantially. *Reduced Vertical Separation Minimums (RVSM)* are evolving and showing great promise. When fully operational, ADS-B, ATOPs, and RVSM will reduce the required aircraft separation substantially. This will improve the efficiency of oceanic routes and reduce controller workload.

UNMANNED AIRCRAFT SYSTEMS REVOLUTION

BACKGROUND

A major change in the area of Airspace Safety has been the rapid growth in the development of Unmanned Aircraft Systems. UAS (often called “Drones” or UAVs) have been around for many years and have proven their value in many military applications. Today, entrepreneurs are exploring new and innovative ways to use drones for commercial purposes. Some examples of applications include law enforcement, package delivery, filmmaking, agriculture, search and rescue, security inspections, photography, real estate listings, etc., and the list goes on and on. The FAA estimates that the drone industry will be a huge boost to the U.S. economy, generating over $80 billion and creating more than 100,000 jobs over the next 10 years. The possibilities for UAS use are endless, and we will undoubtedly see pressure to fully integrate drones safely into the NAS in the coming years.

Section 333 of the *FAA Modernization and Reform Act of 2012 (FMRA)* granted the U.S. Secretary of Transportation the authority to determine whether an airworthiness certificate was required for a UAS to operate safely in the National Airspace System (NAS). FAA began issuing 333 exemptions in September 2014 as a stopgap measure to allow certain low-risk commercial drones to operate while the industry waited for the full regulations. Now, the FAA has issued a new UAS final rule to regulate the operation and certification of *Small Unmanned Aircraft Systems (sUAS).*

FAR Part 107: The Small uas Rule (FAA Safety Briefing)

The Small UAS rule adds a new FAR Part 107 to 14 CFR to allow for routine civil operation of small Unmanned Aircraft Systems (sUAS) in the National Airspace System (NAS) and provide safety rules for those operations. The rule defines small UAS as unmanned aircraft weighing less than 55 pounds. To mitigate risk, this rule limits small UAS to daylight and civil twilight operations with appropriate collision lighting, confined areas of operation, and visual-line-of-sight operations.

The rule addresses airspace restrictions, remote pilot certification, visual observer requirements, and operational limits in order to maintain the safety of the NAS and ensure that small UAS do not pose a threat to national security. Because UAS constitute a quickly changing technology, a key provision of this rule is a waiver mechanism to allow individual operations to deviate from many of the operational restrictions of the rule if the FAA Administrator finds that the proposed operation can safely be conducted under the terms of a certificate of waiver. This new rule became effective August 29, 2016.

It is important to note that FAR Part 107 does not apply to model aircraft like noncommercial drones and radio-controlled aircraft. Model aircraft operators and recreational drone users must continue to satisfy all the criteria specified in Section 336 of the FMRA, including the stipulation they be operated only for hobby or recreational purposes.

Flying Drones Commercially

The new rules are long and complex, so a detailed discussion is beyond the scope of the textbook. Below is a short summary of the basic things an operator must know for flying under the small UAS rule under 14 CFR Part 107.

Pilot Requirements to obtain a Remote Pilot Certificate:

- Must be at least 16 years old
- Must pass an initial aeronautical knowledge test at an FAA-approved knowledge testing center
- Must be vetted by the Transportation Safety Administration (TSA)

(Note: A person who already holds a pilot certificate issued under 14 CFR Part 61 and has successfully completed a flight review within the previous 24 months can complete an approved FAA Part 107 online training course to satisfy this requirement.)

Aircraft Requirements:

- UAS must be less than 55 lb
- Must be registered with the FAA

Operating Rules:

- Drone operation in uncontrolled Class G airspace OK, but otherwise must get permission from ATC in controlled airspace
- Must keep the aircraft in sight (visual line-of-sight)
- Must fly under 400 feet and only during daylight hours
- Must fly at or below 100 mph and yield right of way to manned aircraft
- Must NOT fly over people and must NOT fly from a moving vehicle

(Note: These operating rules are subject to waiver which must be specifically justified by request from the FAA.)

Impact to Air Traffic Control

After the effective date of August 2016, the drone operators that have successfully passed the required knowledge test and received a remote pilot certificate may begin operations in Class G airspace at or below 400 AGL without contacting ATC or issuing a NOTAM. For operations in controlled airspaces (Class B, C, and D airspace, and E surface area) the Air Traffic Control Organization, in collaboration with National Air Traffic Controllers Association (NATCA), is establishing a process where the operator can make a request and receive approval to fly in controlled airspace through an automated system. For more information on the new UAS rule in this quickly changing area, please visit the FAA UAS Web site (www.faa.gov/UAS).

ASRS EXAMPLES

Air traffic controllers face many different challenges every day, regardless of which position they work. However, they also have the ability to improve safety by submitting their accounts of incidents to the ASRS or ATSAP database. Below are a few narratives that show the difficulties that controllers see on a daily basis and their dedication to making ground and air operations safe.

AIR TRAFFIC CONTROL TOWER

Title: Dated facilities affecting controllers' jobs.

> *Aircraft X was cleared to land on the left runway. Aircraft Y was cleared to land on the right runway. My trainee and I were scanning out the window for the aircraft, very difficult due to the scratched and dirty shades and the filthy windows. Also the radar does not differentiate which runway aircraft are lined up for. We saw Aircraft X over the numbers for the right runway in landing configuration. We were forced to send Aircraft Y around, so that we would not lose runway separation. No loss of separation occurred. Get new window sun screens, they are badly scratched and dirty. Clean the filthy windows. Align the radar so that we can tell which runway aircraft are landing on, or add a screen we can enlarge the picture on so we can tell which runway aircraft are lined up for.*

Discussion question for the reader: If you managed the ATC tower described in this incident narrative, what message would you send to your controllers regarding the incident in order to promote safety?

AIR ROUTE TRAFFIC CONTROL CENTER

Title: Separation errors resulting from fatigue.

> *I was getting busy and was feeling very tired and behind the power curve right from the start. I got a Radar Assist position, but was not even able to get him a proper briefing because of the amount of workload I was handling. I did not put 27000 feet in the data tag on this aircraft. It was still showing 29000 feet causing me to turn him right in front of another aircraft at 28000 feet; however, with the proper turns and pilot's immediate actions I was able to maintain separation. I would not have been able to do so if that pilot was not on top of his game. He was GREAT! I have no excuses to make here. We have been super short staffed and with weather throughout our sectors and more than the normal amount of traffic through this sector I am beat and can only pray we get relief from this shortage soon before something worse happens.*

Discussion question for the reader: If you managed the center described in this incident narrative, what message would you send to your controllers regarding the incident in order to promote safety?

CASE STUDY: THE 2006 MIDAIR COLLISION OVER

BRAZIL

Air traffic controllers are tasked with a very difficult and complex job. They must constantly monitor their assigned airspace while maintaining contact with pilots who may need route deviations, altitude changes, and speed adjustments. If at any point air traffic controllers are not fully cognizant of everything going on and not following the safeguards that have been put in place, the results can be fatal. Let us look at the details of an accident in Brazil to demonstrate how ATC is a critically important prerequisite for safety in the skies.

On September 29, 2006, one of the deadliest accidents in Brazilian aviation history occurred, and many have even said that it was the most complex scenarios to investigate in the nation’s history. The crash involved a Boeing 737 from Gol Transportes Airlines operating as GOL Flight 1907 and an Embrarer-136 with U.S. registration number N600XL, operating as an executive aircraft under the company ExcelAire Services. The Embraer jet had departed from São José dos Campos Prof. Urbano Ernesto Stumpf State Airport, and the Boeing jet had departed from Manaus Eduardo Gomes International Airport.

While both flights were on their respective routes, they collided at Flight Level 370. The left wing of each aircraft made contact as they passed with a supersonic closure rate, just barely hitting but in the most catastrophic way, as depicted in Figure 10-3. The Embraer jet lost part of the left winglet, sustained damages in the left stabilizer, and left elevator; however, it remained controllable in flight and made an emergency landing at a military facility. Conversely, the Boeing airliner lost about one-third of the left wing in the collision, making it uncontrollable. The ensuing abrupt spiral dive caused the aircraft to come apart in flight before violently impacting the ground in the middle of the thick rainforest. There were no injuries onboard the Embraer jet, but there were no survivors on the Boeing aircraft due to the brutal crash forces.

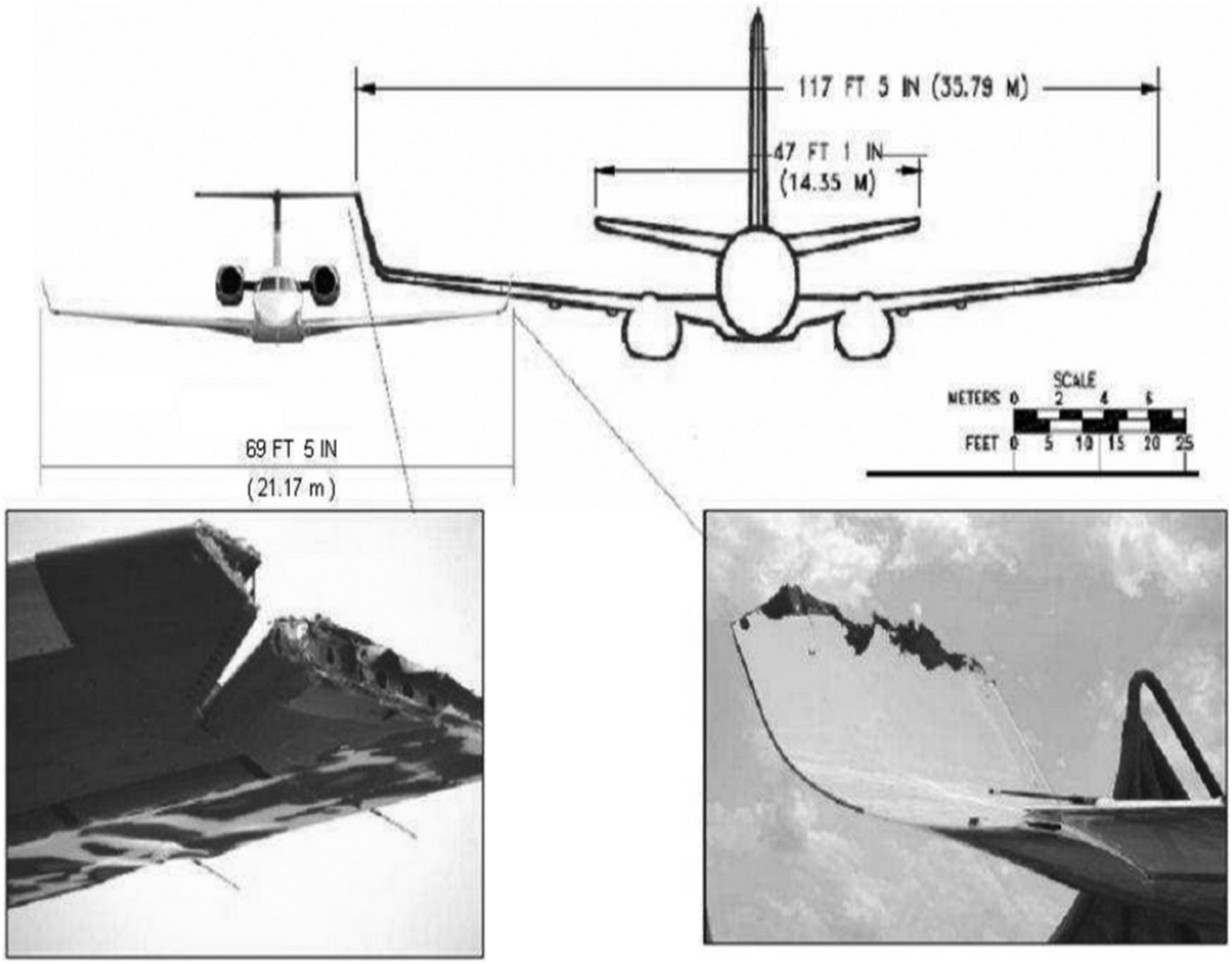

FIGURE 10-3 The geometry of the midair collision. (*Source: Centro de Investigação e Prevenção de Acidentes Aeronáuticos*)

Let us examine the reasons why this midair collision occurred, many of which involve insufficient communication and actions by ATC. Since the safe and orderly flow of traffic requires a team effort that monitors and updates information, it is quite easy for there to be a breakdown somewhere in the system. The contributing factors related to ATC below highlight how lack of sufficient attention from only one party in the system is enough to erode safety:

- There was an incomplete flight clearance issued by the assistant controller in Sao Paulo and the ground controller at São José dos Campos. This caused the Embraer jet pilots to believe they could maintain Flight Level 370 all the way to their destination despite a discrepancy with their flight plan.
- The controller of sectors 5 and 6 in the Brasilia airspace did not provide the controller of sectors 7, 8, and 9 with the necessary information for handing off

the Embraer jet.

- The air traffic controller for sectors 7, 8, and 9 did not make radio contact with Embraer pilots to change the aircraft's flight level and switch the frequency, thus losing contact with the aircraft.
- The air traffic controller of sectors 7, 8, and 9 did not perform the necessary procedures for the loss of transponder and loss of radar. This enabled the Embraer jet to continue flying at the incorrect flight level.
- There was lack of communication between sectors and control centers during the coordination and handoff.
- There was also a lack of monitoring, advisory, and guidance associated with individual ATC decisions at the Brasilia area control center.
- Standard procedures were not followed during the hand offs of both aircraft between controllers and also when radar contact was lost with the Embraer jet.

To prevent a similar midair collision in the future, the accident investigation team made several recommendations for improving ATC communication and procedures. They included the following:

- Instruct the air traffic controllers as to the compliance of the prescribed procedures regarding the air traffic clearances to be transmitted to pilots.
- Ensure that all air traffic controllers fully comply with the prescribed air traffic handoff procedures between adjacent ATC units and/or between operational sectors within the unit.
- Ensure the development of quality management programs for the ATC services in the various control units.
- Ensure that the procedures prescribed for the loss of transponder signal and radar contact, especially within RVSM airspace, are complied with by the ATC units.
- Ensure, by means of a revision of the criteria used in the evaluation of the performance of air traffic controllers, relative to both basic professional formation and radar specialization courses, that they meet the proficiency levels required for the exercise of the activity.

The controllers associated with the Brazil midair collision did not identify and mitigate conflict in airspace, which is an essential job responsibility. In addition, the accident illustrates how accidents are multicausal. There was more than one instance in which controllers did not follow the proper procedures and establish

instance in which controllers did not follow the proper procedures and establish correct communication. For instance, the transponder is an important device for maintaining contact with the pilots. The controllers did not verify the connection, thus disrupting the safety of the airspace. Since the Embraer’s transponder was off, it deactivated the traffic collision avoidance system (TCAS) that may have prevented the collision altogether. So the controllers were only one element of the accident sequence of events, which could have been prevented through the action of others. Unfortunately, there were many factors working against safety that day, and we now must rely on the recommendations to prevent such a tragedy from happening again.

CONCLUSION

It is easy to forget about the role that air traffic controllers play in the aviation field because they are an invisible force. While walking through an airport or waiting on the plane, it is common to see the pilots, flight attendants, and ramp workers; however, the controllers sit tucked away from everyone else. Even though we do not see them, we must not forget the pivotal role they play in aviation. As this chapter has highlighted, the job of an air traffic controller has evolved over the past several decades.

There has been little change in the air traffic system since the 1970s until recent years when the industry has started replacing antiquated technology with new NextGen infrastructure. We will see a shift from equipment like ground-based radar to new programs such as SWIM and DATACOMM under the NextGen framework. Likewise, the tremendous growth in UAS operations will continue to put stress on the ATC system. Despite all the changes, the ultimate goal is to increase the efficiency and effectiveness of communication between pilots, aircraft, and ATC. Doing so will improve processes that prevent midair collisions like the 2006 Brazil accident presented in the case study. Ultimately, everyone in the system must play their part to build the safest environment for our skies and ground operations that we can. Air traffic management and related systems serve as a key component in the commercial aviation safety value chain.

KEY TERMS

Advanced Technologies and Ocean Procedures (ATOPs)
Air Route Traffic Control Centers (ARTCCs)
Airport Surface Detection Equipment, Model X (ASDE-X)
Airport Surveillance Radar (ASR)

Airport Surveillance Radar (ASR)
Airport Traffic Control Towers (ATCTs)
Area Navigation (RNAV)
Automatic Dependent Surveillance—Broadcast (ADS-B)
Collaborative Air Traffic Management Technologies (CATMT)
Controlled Airspace
Data Communications (Data Comm)
FAA Modernization and Reform Act of 2012 (FMRA)
Global Positioning System (GPS)
Instrument Flight Rules (IFR)
Instrument Landing System (ILS)
National Airspace System Voice System (NVS)
Navigational Aids (NAVAIDS)
NextGen Weather
Performance-Based Navigation (PBN)
Positive Controlled Airspace
Reduced Vertical Separation Minimums (RVSM)
Required Navigation Performance (RNP)
Small Unmanned Aircraft Systems (sUAS)
Special Use Airspace
Standard Terminal Automation Replacement System (STARS)
System Wide Information Management (SWIM)
Terminal Automation Modernization and Replacement (TAMR)
Terminal Flight Data Manager (TFDM)
Terminal Radar Approach Control (TRACON)
Traffic Flow Management (TFM)
Uncontrolled Airspace
Unmanned Aircraft Systems (UAS)
VHF Omni-directional Range (VOR)
Visual Flight Rules (VFR)
Wide Area Augmentation System (WAAS)

REVIEW QUESTIONS

1. Describe how air traffic is controlled.
2. What is the mission of the FAA’s ATC system?

3. Identify some of the major milestones in ATC history.
4. What are some of the key components of the ATC system?
5. Discuss the basic differences between visual and instrument flight rules (VFR vs. IFR).
6. What is the purpose of a terminal radar approach control (TRACON)?
7. Briefly describe how GPS works.
8. What are some of the advantages of satellite-based navigation?
9. What is automatic dependent surveillance—broadcast (ADS-B)?
10. Distinguish between ADS-B and ASDE-X.
11. What are the key components of the en route/oceanic ATC system?
12. What is NextGen and what are its goals?
13. Describe what you believe to be the most important of the NextGen backbone programs and express why you made the choice.
14. Discuss the basic provisions of the new FAA Unmanned Aircraft Systems Rule (FAR Part 107).

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CHAPTER ELEVEN

SAFETY DATA

LEARNING OBJECTIVES

After completing this chapter, you should be able to

- Explain why the accident rate is a better measure of safety than accident counts.
- Discuss considerations and caveats when analyzing and comparing commercial aviation accident statistics.
- Understand trends and major elements of Boeing's *Summary of Commercial Jet Transport Aircraft Accidents*.

- Discuss OSHA injury and illness rate statistics.

INTRODUCTION

In passenger transportation, *safety factors* (some of which are *causal factors*) are events that are associated with or influence fatality rates. A *safety indicator* is a measurable safety factor. The *probability* of death or injury as a result of traveling in a given transportation mode, when quantified, is the primary benchmark of passenger safety. Car accident rates also are commonly used as safety indicators since most passenger fatalities occur as a result of terrestrial vehicle accidents and not aviation ones.

If one were to look at risk as the probability of death, then the risk due to traveling can be established from fatality rates. However, commercial aviation fatality rates are poor indicators to show change in short-term risk since a large jet accident can potentially result in the deaths of a few hundred people. Hence, a single accident can greatly influence fatality rates. Therefore, the trending of fatality rates requires data from extended time periods (5 years or more). As an alternative process, accident rates can be used instead of fatality rates as indicators of safety levels. The number of fatalities, even for a specific type of accident, varies greatly with each crash. However, while the number of accidents may have a narrower range of annual variance than the number of fatalities, it still presents challenges for analyses. While the way that accidents are defined may mean that there are more numbers of accidents than fatalities, modern commercial aviation thankfully presents few accidents making for difficult statistical analyses. Also, the number of accidents in a given country, geographic area, or type of operation can vary significantly from one year to the next, thus resulting in accident rates also being poor indicators of short-term estimates of risk trends.

Before using accident statistics for safety analyses, it is necessary to understand the denominators of *exposure* used to calculate transportation accident or fatality rates. *Exposure data* can be thought of as an indication of the amount of opportunity an event has to occur. Cycles, distance, and time for passengers and vehicles are the principal exposure types. They are used in the denominator of rates, such as fatalities per passenger departure or electrical system failures per flight-hour. The choice of type of exposure data will affect how rates are compared between and within transportation modes. We must be careful to only compare rates that have the same units of exposure. For example, it would be highly confusing to compare fatalities per departure in one year to

fatalities per flight hour in another year.

Passenger-miles (the number of passengers multiplied by the miles traveled) are most appropriate when one is comparing air transportation with other modes of transportation, as they allow generalized, broad-based system comparisons. Using trips between the same city pairs to compare risks for different modes of travel seems appealing at first glance; however, the number of city pairs in the United States is extremely large and some modes of transportation do not have passenger data in the format required for this type of comparison. In addition, risk per passenger-mile is not uniform over a trip and can vary by the type of route taken, by season, or the time of day.

It is clear that the probability of an accident is significantly higher during takeoff or landing given the increased risk in such phases of flight over others such as cruise. Since the cruise phase is usually the longest part of any commercial flight, then most travel time occurs under a lower average risk. Such variation is not present during surface transportations, such as during the daily commute to one’s office, although specific locations may pose more driving hazards than others. Aviation accidents can vary greatly in severity, ranging from a flight-attendant back injury from pushing carts during in-flight service or handling overhead luggage to several hundred deaths due to an aircraft crash. To render a more equitable perspective on aviation risk, some databases categorize accidents as fatal and nonfatal. However, even when using such a process, a single death on a ramp during an aircraft pushback would still be classified as an aviation accident even though the aircraft involved in the accident is untouched. To address this issue, International Civil Aviation Organization (ICAO) classifies accidents as *major*, *serious*, *injury*, *or damage* (see definitions in Chapter 1). Another classification popular with insurance and aircraft manufacturing industries is to refer to accidents as either an (aircraft) *hull loss* or non-hull loss. A hull loss is airplane damage that is beyond economic repair, which implies that very serious damage was incurred.

Accident counts by themselves cannot be reliably used to measure relative safety among different airlines or flight departments because there are just not enough accidents for statistics to be usable. Most airlines will, thankfully, not have a hull loss in any given year, making comparison based on such criteria meaningless. Small numbers of accidents, even if including all four accident categories used by the NTSB, may produce a false picture due to highly unpredictable events, such as turbulence encounters.

Furthermore, all other considerations being equal, an airline that has a larger fleet of aircraft could be expected (statistically speaking) to have a larger number

of accidents than an airline with fewer planes. Similarly, aircraft models that are flown more often would be expected to be involved in more accidents than less frequently used models. For this reason the *accident rate*, which is the number of accidents divided by some common base variable (e.g., flight hours, departures, and miles flown), is a more valid indicator of relative safety than just accident counts. In this context, time (flight hours) is a popular measure of exposure in many types of risk analysis. Since flight-hour data is needed for economic, operational, and maintenance reasons, airlines keep accurate records of such data which are readily available for safety rate comparisons. Also, rate data is used by NTSB to compare safety performances among airlines and other sectors of the air transportation industry.

Even when comparing rates versus number of accidents, context must be considered in order to perform a fair analysis. For example, weather is often a factor in accidents and some airlines operate primarily in relatively benign weather, such as is often found in the desert southwestern United States or Mediterranean Europe. While others operate in very challenging weather, such as in Canada, Alaska, Scotland, or Scandinavia, where large portions of the year require operating in frozen precipitation, contaminated runways, and low ceilings. Another example is the variation in navigation aids and airport conditions faced in different parts of the world. Airlines providing service within Europe may expect radar control and precision approaches to long paved runways, whereas some airlines in South America and Africa routinely operate in non-radar environments to dirt runways in the jungle.

As previously mentioned, takeoffs and landings, to include approaches, present more risk than other phases of flight. This is partly because there is less time to correct undesirable aircraft states or errors before being met with the unforgiving firmness of terrain or fluidity of water. If takeoffs or landings are used as a base for rate calculations, then the airline that predominantly flies several shorter routes but similar number of hours per day would be expected to have a higher accident rate than those flying only a few longer legs. For example, a twin engine turboprop aircraft flying tourists around Alaska may make 10 flights per day and therefore the same amount of takeoffs and landings, whereas a legacy airline’s Boeing 787 may make one flight per day. A safety analyst desiring to assess accident rates between two such operators would be wise to use number of landings as a denominator in the accident rate equation versus flight hours in order to produce a more equitable comparison.

The air transportation industry is extremely dynamic and changes with technological advances, operational strategies (point-to-point versus hub and spoke), mergers, consolidations, and bankruptcies that all rapidly change the

aviation landscape. The aviation industry of today is very different from what it was 40 years ago. For all these described reasons, one should also exercise care when comparing safety statistics over long periods of time. While there is no clear answer as to what time domain is appropriate for analyzing and comparing aviation safety data, the most recent 5-to 10-year span appears to be the accepted norm among federal regulators.

Aviation accidents are rare occurrences, and the risk of death or serious injury by air travel is miniscule. With such small numbers, making statistical inferences from the data to evaluate safety performance of the industry is very difficult. Regulatory agencies and the aviation industry maintain a wide variety of safety-related information. However, one must take into consideration the accuracy and completeness of these data when developing safety trends and recommending control measures. Safety factors other than fatalities or accidents that include the nature and causes of accidents (covered in Chapter 2) should be studied and used for preemptive strikes against safety hazards and to provide timely feedback to safety managers and policymakers.

In summary, no single measurement provides the complete safety picture. Passenger-exposure data are used when passenger risk is to be described. Passenger-miles are used when the influence of vehicle size or vehicle speed on the data is nonexistent. Departure-exposure data accounts for nonuniform risk over a trip. Time is the most widely used exposure measure, and time-based data are often readily available.

AVIATION ACCIDENT AND SAFETY STATISTICS

Chapter 7 reviewed various data reporting systems, both voluntary and mandatory, that are used in aviation. While ensuring compliance or consistency in safety reporting is difficult in general, voluntary systems have added complexity in that they are inconsistent and less reliable because they are subject to reporting bias and erroneous content. Such reports can still be highly valuable, of course. There are several reliable sources of accident data. One of the most easily accessible accident databases is maintained by Boeing, which publishes an annual *Statistical Summary of Commercial Jet Airplane Accidents*. Another source is the Aviation Safety Network of the Flight Safety Foundation, found at http://aviation-safety.net/. Finally, the definite source of aircraft accident data in the United States is the NTSB database.

MANUFACTURERS' INVOLVEMENT WITH SAFETY DATA

Safety professionals within the airframe and engine manufacturer community can often be found at accident sites participating in the investigation due to their unique, equipment-specific knowledge. They collect data and analyze them with their expertise and their extensive network of fellow experts on given systems back at their company. They recommend improvements in the way aircraft are designed, built, operated, and maintained. The goal for all who participate in accident investigations is to learn from the event, and therefore, prevent future accidents. Such prevention is best accomplished when the equipment experts are allowed to yield their unique insights as part of the investigative process.

While different manufacturers all participate in the investigative process when their respective equipment is involved, organizations are often organized differently from each other and, consequently, may also approach the investigative process differently. For example, accident investigation and safety data analysis are separate units at Boeing, while at other manufacturers, they are combined and often linked to customer support in a single organization.

The closest thing to a constant among manufacturers' safety departments is their responsibility for accident investigation. When a company's product is involved in an accident, the company has a duty to help find the causes. In the parlance of the NTSB, the company becomes a *party* to the investigation, as discussed in Chapter 6. That means the manufacturer's representatives work alongside NTSB investigators in examining evidence at the accident site. The parties conduct subsequent tests and suggest findings, but the final analysis and published report are produced by the NTSB.

Safety departments with manufacturing companies scrutinize incidents as well as accidents. Committees are formed to represent various departments using new safety management systems (SMS) procedures. Doing so is part of the overall evolution from reactive safety to proactive safety, as discussed in Chapter 7, and as part of the SMS framework presented in Chapter 12.

Based on the events reviewed, the committees recommend design changes or revisions in maintenance or operating procedures. Accident reports produce a lot of data, but the lack of frequency of accidents compared to the frequency of incidents means that still more data come from incident reports and other report files compiled by airlines, manufacturers, and government agencies. The FAA, for example, records *Service Difficulty Reports*. Manufacturers' safety departments have come to view these reports as a resource to be developed and cultivated. The data come from a variety of sources. Manufacturers' service representatives around the world report regularly on anomalous events both large and small.

Airlines often report issues directly to manufacturers for both prompt, remedial action input and overall tracking of discrepancies for any given part or system. Other data sources include civil authorities and international organizations such as the International Air Transport Association, the U.K. CAA, and U.S. FAA, as well as insurance underwriters and publications. Even with all those collection efforts, safety staff do not claim that a record of every event unfailingly finds its way to the appropriate database. When little or no damage is involved, airlines sometimes make no external reports due to the very high tempo of technical operations and the never ending list of repairs and inspections that demand constant attention.

While manufacturers of large airframes maintain what probably are the most extensive databases, other manufacturers also are collecting such information. Makers of engines and other components are also in the business of collecting statistical data. The purpose of gathering the data is trend analysis. Computers may be able to discern patterns that a human analyst may miss. Boeing has taken a proactive stance in the area of safety. Manufacturers can alert carriers to problems they did not know they had. A team assembled by Boeing uses accident records and other data to identify current safety issues. For example, Boeing was a leading proponent in stressing the importance of installing ground proximity warning system (GPWS) and the need for proper training in its use.

Similarly, to prevent approach and landing accidents, Boeing has urged that every runway used by commercial transports be equipped with an instrument landing system (ILS) and several training measures have been advocated for pilots and controllers to alleviate the dangers associated with nonstabilized approaches.

Boeing research also has addressed *crew-caused accidents*. Its data and other sources identify flight crew error as the primary cause in close to 70% of commercial jet hull-loss accidents (see the next section "Boeing's Accident Statistical Summary"). However, accidents rarely have a single cause. Manufacturers' prevention strategies address all the factors, not just the primary one. Removing even one link in the chain of events can prevent many accidents.

Airlines maintain databases and conduct trend analyses of their own. These analyses can benefit from work done by the manufacturers. For example, American Airlines studied a series of Boeing 757 tail strikes. After assessing its own records, the carrier checked with Boeing about the experiences of other operators of the same type of aircraft. Once the problem was identified, American Airlines and Boeing worked to solve it by revising training methods.

The large airframe manufacturers also publish annual reports that are compilations of industry-wide accident data. It should also be noted that, for

compilations of industry-wide accident data. It should also be noted that, for day-to-day problem-solving, airlines usually have more contact with a manufacturer's accident and incident investigators than with the analysts behind the data. In the discussions that follow, databases from Boeing, the Flight Safety Foundation, and the NTSB will be explored to analyze aviation accident statistics.

BOEING'S ACCIDENT STATISTICAL SUMMARY

According to the Boeing's accident statistical summary, in the 50 years plus, worldwide history of scheduled commercial jet operations (1959 to 2015), there have been 1,918 accidents resulting in 29,646 onboard fatalities and 1,216 external fatalities. Of the 1,918 accidents, 619 produced fatal and 973 resulted in hull losses.

If one were to consider accidents by type of operation, 80% (1,525) of the 1,918 accidents were passenger operations, 14% (269) were cargo operations, and the remaining 6% (124) occurred during testing, training, demonstration, or ferrying. U.S. and Canadian operations collectively incurred about 30% (571) of the 1,918 worldwide accidents, contributing to about 21% (6,202) of the 29,646 global onboard fatalities. Over this period, there have been in excess of 713 million cumulative departures and more than 1,321 million cumulative flight hours. The industry is now operating 24,611 jet aircraft, with little over 27 million departures each year.

If we examine a plot of all accidents for the worldwide commercial jet fleet for the period 1959 to 2015, as shown in Figure 11-1, we can see that the rates for all accidents and those involving hull losses appear fairly stable for the past 40 years. Closer inspection, though, reveals a steady and continuous decrease until reaching an asymptotic state in the past two decades. However, even if this low accident rate remains constant over the next few years, we can expect to see an increase in the actual number of hull-loss accidents each year as the fleet increases in number of departures.

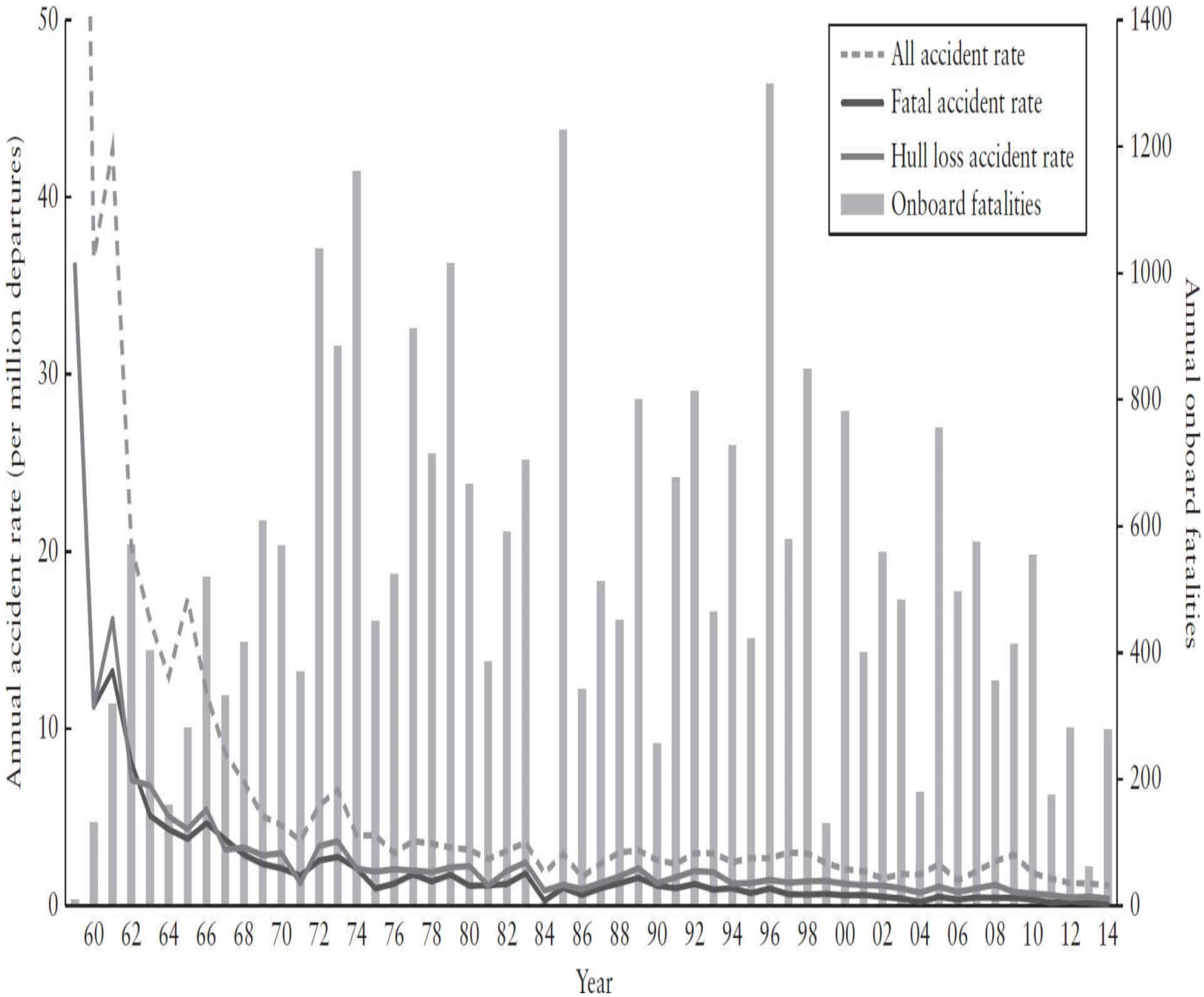

FIGURE 11-1 Accident rates and fatalities by year; all accidents, worldwide commercial jet fleet, 1959–2015. (*Source: Boeing 2015 Statistical Summary, July 2016*)

Hull losses and fatal accidents were also analyzed according to the phase of flight in which they occurred (Figure 11-2). The combined final approach-and-landing phases accounted for 49% of the hull-loss and fatal accidents, followed by the combined phases from loading through initial climb (23%). Cruise, which accounts for about 57% of flight time in a 1.5-hour flight, occasioned only 12% of hull-loss accidents.

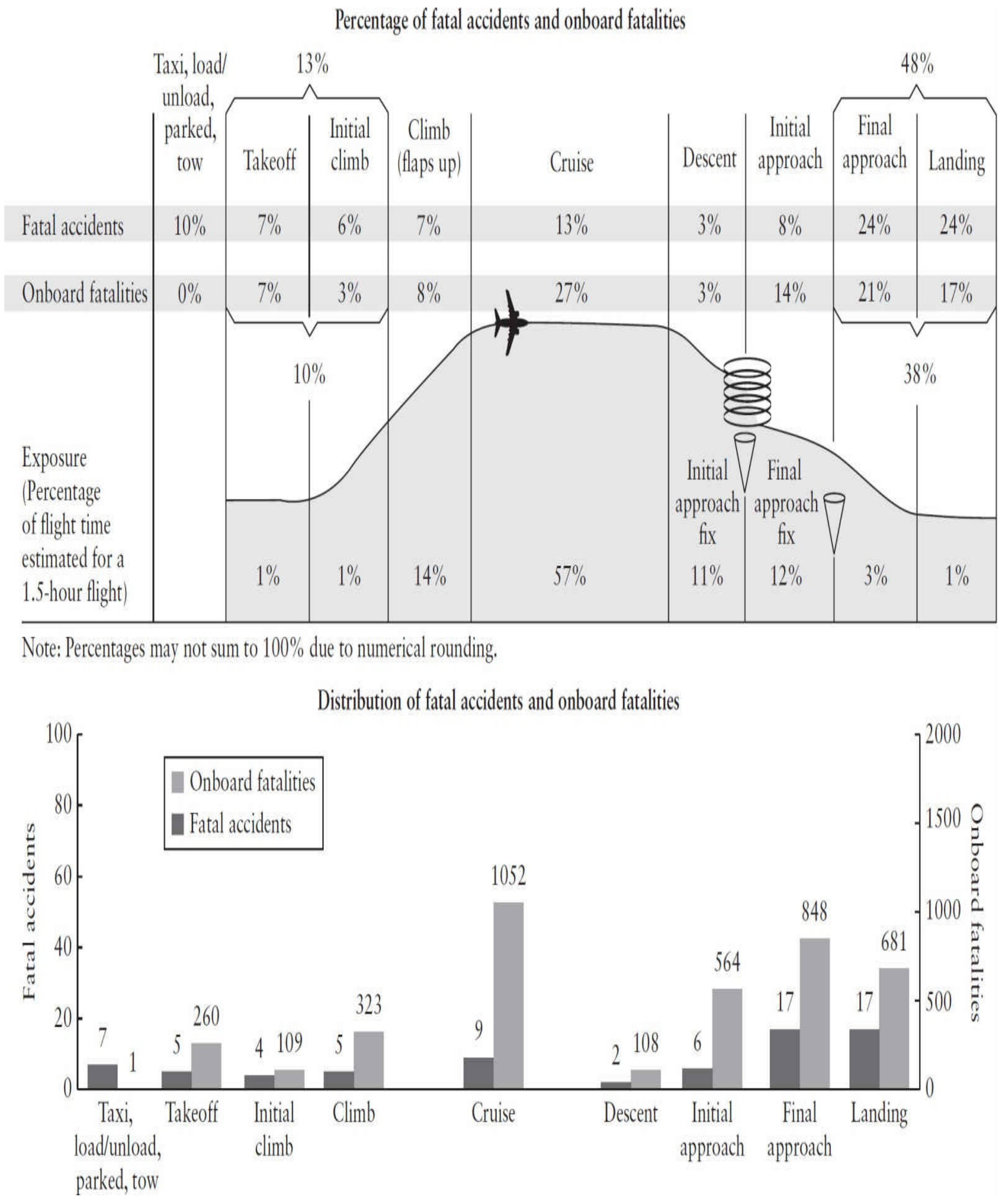

FIGURE 11-2 Accidents and onboard fatalities by phase of flight; hull-loss and/or fatal accidents, worldwide commercial jet fleet, 1992–2015. (*Source: Boeing 2015 Statistical Summary, July 2016*)

In past years and in the previous editions of this book, the summary also considered primary causal factors for commercial operation hull-loss accidents.

Classifications occurred for primary causes as attributed to flight crew, airplane, weather, maintenance, airport/ATC, or miscellaneous/other. However, Boeing has recently stopped reporting this data in adherence with emergence philosophies described earlier in this book about the risks of such monocausal assignments. Finally, fatalities by accident categories were covered for the period 1960 to 2015 (Figure 11-3). Loss of control in flight accounted for 1,396 onboard fatalities, followed by runway excursions, which had 632 onboard fatalities and 35 external fatalities during the recent 15-year period.

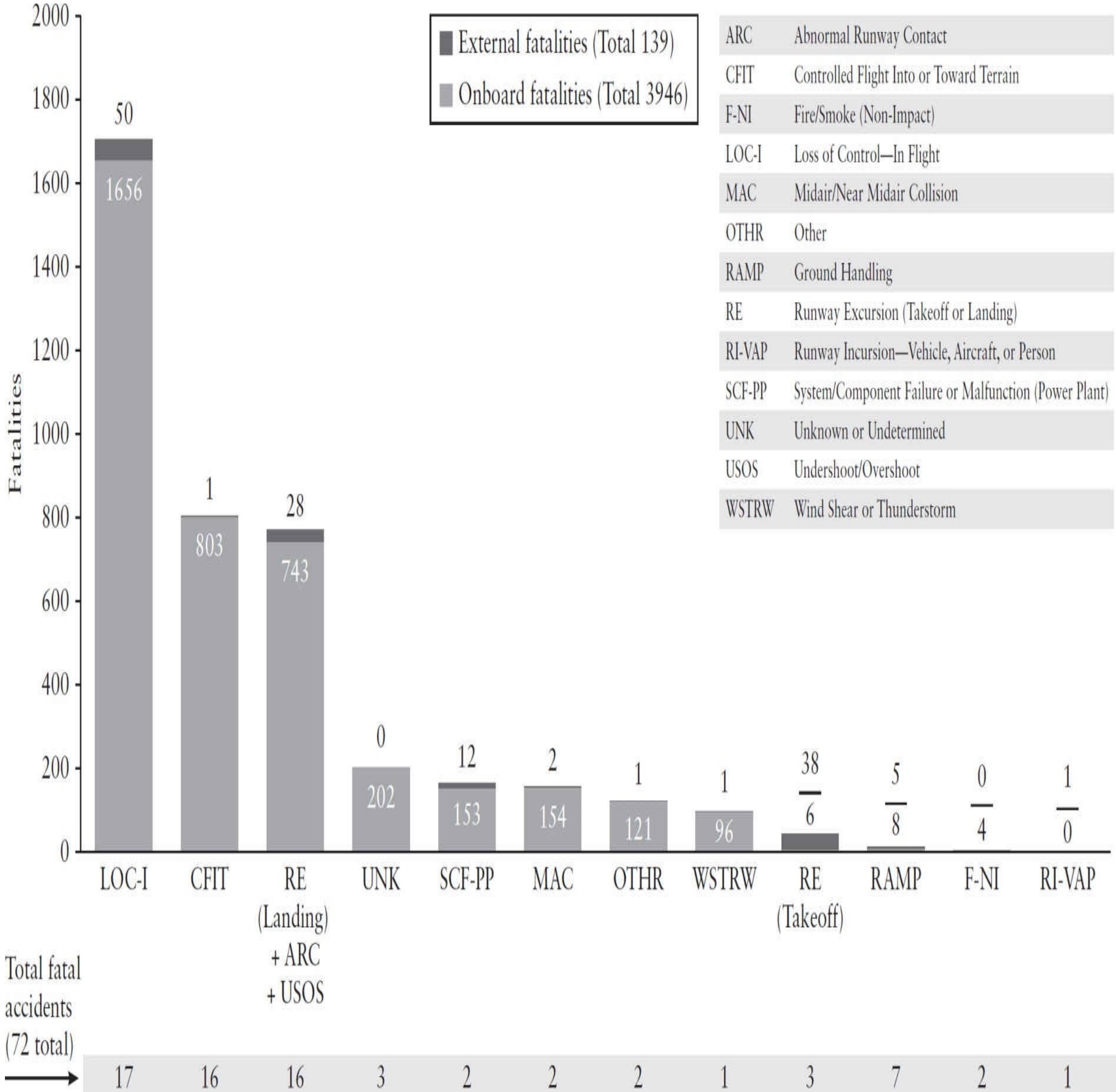

FIGURE 11-3 Fatalities by accident categories, fatal accidents, worldwide commercial jet fleet, 2000–2015. (*Source: Boeing 2015 Statistical Summary, July 2016*)

The three figures (Figures 11-1, 11-2, and 11-3) can be used as a launching platform for countless discussions about accident measurement, accident causes, and accident outcomes in terms of severity. For example, Figure 11-1 prompts thoughts about how different initiatives over the past century of flight have been used as links in the commercial aviation safety value chain. This includes the advent of jet engines with high mechanical reliability, the use of flight simulators in pilot training, and different maintenance inspection techniques that catch incipient problems before they become catastrophic.

Similarly, Figure 11-2 can elicit a spirited discussion about the role played by aircraft status in the severity of outcomes as a function of the phase of flight when an event occurs. An additional area for discussion is that of exposure to different internal and external threats to the operation of aircraft.

Lastly, Figure 11-3 prompts the reader to ask whether the relative distribution of accident categories has remained fixed or has changed over time. The same discussion can be projected into the future by exploring how the relative distributions may change with increased reliance on automation in both flight deck operations and external safety systems such as those found in airfield operations and air traffic control.

These three figures are representative of the whole report and of the even larger use of data and statistics for managing safety. As such, it is evident that their use helps prompt questions and analyses that shed light on different issues in safety and assist with evidence-based decision making by government officials, airline managers, and manufacturers.

It should be noted that Boeing’s accident data exclude turboprop aircraft as well as those with maximum gross weights of 60,000 lb (27,216 kg) or less; Soviet Union and Commonwealth of Independent States accidents; and accidents resulting from sabotage, hijacking, suicide, and military action. Although it is not an exhaustive compilation of data, and therefore only offers a partial statistical analysis, the content still proves highly useful for determining safety initiatives.

Based largely on data such as these, it has become increasingly apparent that the largest challenge facing airline safety management continues to be human error. This recognition is not new. In 1974, the Flight Safety Foundation held its 28th Annual International Aviation Safety Seminar in Williamsburg, VA. The theme was human factors in flight operations, and it is believed that this seminar was the first major airline industry safety conference devoted to human error. In 1975, International Air Transport Association (IATA) sponsored its 20th Technical Conference: Safety in Flight Operations. The conference proceedings were almost exclusively focused on human factors and human-error issues

were almost exclusively focused on human factors and human error issues, which were termed “the last frontier of aviation safety.” These early industry efforts were at the vanguard of present-day approaches to the problem of management and control of human error in aviation operations.

The University of Texas’ Human Factors Research Project conducted aviation safety research funded by the FAA and industry for over 25 years. More recently, a current safety initiative of the Flight Safety Foundation is a project entitled “Operators Guide to Human Factors in Aviation” and contains an extensive compendium of Human Factors information on their Web site (flightsafety.org). The Flight Safety Foundation, in conjunction with AIRBUS, established an annual Human Factors in Aviation Safety Award which is presented at the FSF European Aviation Safety Seminar. Likewise, IATA and ICAO are very active in Human Factors training on an international basis. The subject of Human Factors has been thoroughly explored earlier in Chapters 3 and 4 of this textbook.

UNITED STATES’ STATISTICS

For the United States, the primary source of accident data is the NTSB. Because of the NTSB’s very broad definition of an accident, the United States experiences an average of close to 36 accidents involving scheduled and nonscheduled air service each year. However, serious accidents, those involving fatalities, are much rarer. The NTSB’s official compilation of accident statistics from 1995 to 2014 for Part 121 scheduled and nonscheduled airline service provides excellent insights into the state of modern commercial aviation safety in the United States.

In that transportation segment, the country averages 20 to 50 accidents per year of which only 0 to 6 accidents are fatal accidents with 0 to 525 onboard fatalities per year. Such numbers do not mean much unless a rate can be derived by comparing them to flight time or departures as a measure of exposure. The NTSB also calculates that in a year period there are between 13 and 20 million flight hours and between 8 and 11 million departures. Therefore, the accident rate can be calculated as being between 0.17 and 0.3 accidents per 100,000 flight hours and between 0.06 and 0.036 fatal accidents per 100,000 flight hours.

When using departures as the denominator to calculate the rates, the NTSB numbers show that between 0.248 and 0.52 accidents occurred for each 100,000 departures and between 0.009 and 0.061 fatal accidents occurred per 100,000 departures. The difference in numerators is because not all accidents involve fatalities. Although such numbers are still not acceptable to the traveling public and to those affected by the tragedies represented by each fatal accident, the

and to those affected by the tragedies represented by each fatal accident, the overall picture for commercial aviation safety is quite positive. It should be noted that the September 2001 terrorist attacks are excluded from this analysis since they were intentional acts that fall under the domain of security, and therefore, are not safety-related.

As a form of comparison to other transportation modes, the NTSB Web site also provided preliminary estimates of measurements for fatalities in 2013 associated with highway (cars, trucks, motorcycles, etc.), marine (ships), and rail (trains) modes. The year 2013 was the most current year for such an inter-modal comparison. In aviation there were 443 fatalities that year, of which only 9 were associated with the airlines and 6 with commuter categories. The vast majority of aviation fatalities, 387, were associated with general aviation. By comparison there were 615 marine fatalities that same year and 891 rail fatalities. As one might expect, the number for highway fatalities is startlingly higher at 32,719 for that same year. Granted, the reader should be cautious when comparing between statistics that are bereft of exposure data.

For such a purpose we can reference the statistical analysis performed by the Airlines for America, which is an American trade association and lobbying group that represents the largest airlines and which is based in Washington, D.C. The analysis draws on other sources of data, such as those from the National Safety Council, the American Public Transit Association, the Federal Railroad Administration, and the NTSB. The analysis depicts the big picture by stating that overall about 2 out of every 10 unintentional injury-related deaths occur in passenger transportation. Unintentional deaths exclude suicide and homicide. However, the risk of passenger death, as expressed on a per 100 million passenger mile basis for travel from 2010 to 2012, is 0.49 for light duty vehicles (e.g., cars, SUVs, light trucks, and vans), 0.05 for buses, 0.02 for trains, and 0 for airlines. In fact, from 2010 through 2015, there were zero fatal accidents for U.S. airlines. Thus, it can be said with confidence that commercial aviation is the safest mode of transportation in the United States.

Global Statistics

On an international scale, statistics are available from both governmental and private sources. On the government side, every year ICAO publishes a readily accessible and very detailed safety report that depicts accident statistics and concomitant analyses. The latest such report, published in 2016 and containing data through 2015, shows an ongoing, year-over-year improvement in both the number of accidents as well as the accident rate. The global accident rate

involving scheduled commercial operations dropped by 7% from 3 to 2.8 accidents per million departures from 2014 to 2015, and, indeed, the number of fatal accidents in 2015 was down to 6, representing the lowest number in the past 5 years. Also, the 474 fatalities in 2015 were a significant decrease from the 904 fatalities in 2014.

On the private side, IATA is a trade association for the world's airlines, comprising 268 airlines from 117 countries. According to IATA, in 2015 there were 37.6 million flights and approximately 3.5 billion passengers. Despite the high volume of flights, only 68 commercial airline accidents occurred. Of these 68 accidents, only 4 resulted in passenger fatalities. It is important to note here that Germanwings Flight 9525 and Metrojet Flight 9268 were not included in the data since they were classified as deliberate acts of unlawful interference. The 2015 figure represents a decline from the 77 accidents in 2014. More good news is that during the 5-year period from 2010 to 2014, the average rate of accidents per year was 90. From this, we can see that the long-term trend indicates that flying is continuing to get safer. The IATA numbers represent a different way of measuring the same aspects of safety as those of ICAO. Both approaches show continued improvement and that commercial aviation is overall a very safe mode of transport.

OCCUPATIONAL ACCIDENT STATISTICS—DEPARTMENTOF LABOR, BUREAU OF LABOR STATISTICS (BLS)

Commercial aviation safety also requires protecting the very large portion of the workforce that falls outside of flight crews, such as the ramp agents, airfield managers, aviation maintenance technicians, dispatchers, and air traffic controllers, from harm.

The death toll trend due to occupational injuries has been on the decline over the past decades because of new technology, stricter safety regulations, and a shift in the economy toward safer service-industry jobs. The Census of Fatal Occupational Injuries program reported that the number of fatal work injuries in the United States in 2014 was 4,821, slightly up from 4,585 in 2013. Even though there has been variability in this figure over the past 10 years, there is no significant trend to indicate if workplace fatalities are up or down for the 5-to 10-year window that we like to use for analyzing and comparing aviation safety data. Overall though, the transportation industry still suffers from the most work-related fatalities than any other sector.

The *Bureau of Labor Statistics (BLS)* still remains the authoritative source for nonfatal occupational (work-related) illnesses and injuries in the United States. The BLS, in cooperation with OSHA and the state government agencies in the United States, uses scientifically developed sampling surveys to collect data on nonfatal injuries and illnesses. All deaths are reported directly to OSHA. The surveys exclude the self-employed farms with fewer than 11 employees, private households, federal government agencies, and employees in state and local governments. The results are published in the *Standard Industrial Classification (SIC) Manual*, which was first developed and published in 1987. Information in the SIC Manual is published by industry type. Major groups are further divided into industry groups with each industry group having SIC codes within it.

North American Industry Classification System (NAICS)

Developed in cooperation with Canada and Mexico, the *North American Industry Classification System (NAICS)* represents a profound change in government statistical reporting programs. NAICS uses a six-digit coding system to classify all economic activity into 20 service sectors. For example, the category of “Scheduled Air Transportation” is broken down into two codes as follows: 481111, “Scheduled Passenger Air Transportation,” and 481112, “Scheduled Freight Air Transportation.” The NAICS has been adopted to soon replace the Department of Labor’s SIC coding system, thus providing a new statistical tool in the area of occupational accident statistics.

The BLS Injuries, Illness, and Facilities program provides annual information on the rate and number of work-related injuries, illnesses, and fatal injuries, and how these statistics vary by incident, industry, geography, occupation, and other characteristics.

In recent years, the number of work-related fatalities, injuries, and illnesses has steadily decreased in the Air Transportation subsector, NAICS category 481. For example, the number of fatalities in this subsector decreased from 38 in 2008 to 28 in 2009, which represents a significant reduction. Similarly, the rate of injury and illness cases fell for the category of total recordable cases. This includes incidents that involve days away from work and days of job transfer or restriction. However, when compared with general industry injury and illness trends, the air transportation rates are 8.5 total recordable cases per 100 full-time workers, which is nearly twice the national injury average. While general industry injury and illness trends have been at their lowest level in years, the air transportation sector could still use some significant improvement.

Like many collected data, the NAICS/BLS statistics have some limitations.

As with most surveys, the data are subject to sampling error. There are also other sources of error, such as the inability to obtain information about all cases in the sample, mistakes in coding or recording data, and difficulties reaching agreement on certain definitions that define data to be used for analyses. Furthermore, since these statistics provide an estimate of workplace injuries and illnesses based on logs kept by employers during the year, the collection process is only as good as the employers' understanding of which cases are work-related under OSHA's recordkeeping guidelines. Finally, the number of injuries and illnesses that get reported can be influenced by the level of economic activity, working conditions, work practices, worker experience and training, and the number of hours worked.

CONCLUSION

In his autobiography, Mark Twain references the following quote: "there are three kinds of lies: lies, damned lies and statistics." This saying goes on to show how people often use numbers to strengthen their arguments at the risk of misrepresenting meaning if not used carefully. In aviation, statistics are used to measure safety and to provide evidence to justify safety recommendations. The range of safety issues present in aviation includes minor sprains and injuries all the way to major catastrophic accidents. Therefore, we cannot rely solely on one calculation to accurately paint the picture of the safety landscape. Instead, we must put everything together, whether it is data from the NTSB, IATA, manufacturers, BLS, or OSHA, to get a holistic view of the safety scene.

Although no single measure can indicate the overall status of safety in an organization, individual statistics by themselves are still helpful for determining smaller aspects of safety. They can assist us in identifying weak links in the commercial aviation safety value chain. Ultimately though, the goal is to continue to reduce the number of fatal accidents per year, and we can do this by crafting a variety of measures in response to properly collected and analyzed safety data.

KEY TERMS

Accident Rate
Bureau of Labor Statistics (BLS)
Crew-Caused Accidents
Exposure Data

Hull Loss
Major, Serious, Injury, or Damage Accident
North American Industry Classification System (NAICS)
Probability
Safety Factors
Safety Indicator
Service Difficulty Reports
Standard Industrial Classification (SIC) Manual

REVIEW QUESTIONS

1. Why is the accident rate a better measure of safety than accident counts?
2. Discuss some of the issues associated with analyzing and comparing commercial aviation accident statistics.
3. Explain why aviation safety statistics are calculated differently than ones for other modes of transportation.
4. Why is it important to open and sustain a dialogue about safety statistics among all players in the aviation industry?
5. How does trend analysis contribute to analyzing safety?
6. What are some lessons that can be learned from the Boeing summary?
7. Explain how OSHA injury and illness rates are calculated.
8. What are SIC and NAICS codes and how are they used?
9. How do OSHA injury and illness rates relate to the safety of aviation's operating environment?

SUGGESTED READING

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CHAPTER TWELVE

MANAGING SAFETY

LEARNING OBJECTIVES

After completing this chapter, you should be able to

- Discuss the evolution (history) of Safety Management Systems (SMS) principles.
- Define and discuss the features of the Four Components (Pillars) of SMS.
- Compare and contrast the differences between a hazard and a safety risk.
- Discuss the significance of the *Probability* × *Severity* = *Risk* formula.
- Explain the purpose of the risk assessment *5 × 5 Matrix* in terms of probability and severity.
- Discuss the significance of reducing risk to a level as low as reasonable practicable (ALARP).
- Describe the role of unions in airline safety.
- Describe the principle elements of the safety assurance process.
- Discuss the role of auditing in the safety assurance process.
- Discuss the role of accident investigation in commercial aviation SMS.
- Explain the importance of communications to an effective airline safety program.
- Discuss the international development aspects of SMS.
- Explain the development of airline SMS in the United States.
- Explain the phased SMS implementation process.
- Discuss some of the challenges of SMS implementation.

INTRODUCTION

Safety Management Systems (SMS) is a term describing a standardized approach to controlling risk across an entire organization that promotes the sharing of safety data and best practices. SMS requires crafting policy, methodically calculating and controlling risk, measuring how everything is working, and communicating it all to employees. A commercial airline, like any other major business, has to integrate and manage a complex array of tasks to deliver products and services to the customer. Safety must be built into every aspect as an integral part of every employee’s job responsibility. After all, safety is a team effort. This book has repeatedly used the expression of a safety value chain to

describe how every employee and technology are links in the chain, and chains are only as strong as the weakest link. The airline industry has always placed great emphasis on safety and has moved aggressively to identify and control problems that cause accidents. Airlines have learned, sometimes the hard way, that active management of risk is an absolute requirement for a healthy company.

Even though the management of safety is not a new concept, it was not until the 1990s that safety professionals started seriously asking the rather profound question of whether they were managing safety at peak efficiency. This introspective question may have been prompted by recognition of the safety professional's role in an organization, by increased public awareness that advances in scientific and business principles can be applied to management for making any operation more efficient, and that safety is a state that requires management.

It was probably the convergence of those lines of thinking, combined with the traveling public's increasing intolerance of inefficiency, which led to the birth of a standardized approach to minimizing risk, which today we call Safety Management Systems (SMS). Although safety management as a practice has existed since the birth of aviation, in one way or another, SMS is a formal and standardized framework of best practices for running a safety program based around sophisticated business and scientific processes. Those processes are not just used to create safety, but also used to monitor the health and effectiveness of a safety program so that it operates at peak performance. A key component of the architecture mirrors the business world's use of performance indicators. In SMS, these are called safety performance indicators.

An ideal airline SMS would have unlimited resources to manage the safety demands of the business. If that were the case, the management of safety would not be that difficult. However, since commercial aviation is in the business of making profit and any investment in safety requires people, time, and money, limited resources force airlines to choose wisely about how to allocate their funds. Safety efficiency, therefore, is not just about making risk management more streamlined and effective, but also about saving money by operating a safety program as lean as possible without seeing significant safety issues arise.

Safety and efficiency of airline services should never be in competition, rather they should be in balance during management's decision-making process. Although safety is a major function and should permeate through all departments, it is not the main objective of the commercial airline industry. Ultimately, an airline's primary goal, as with any business, is profit. Airlines sell a promise to get passengers from one destination to the next. Although safety

contributes to fulfilling this promise, so do monetary factors such as punctuality, cost-effectiveness, and predictability. The dichotomy between safety and profit can be perceived as being in conflict because safety can be very expensive. The champions of safety see their expenditures as investments to prevent future catastrophes and often say, “Safety may be expensive, but not nearly as expensive as the lack of safety.” A company’s managers may sometimes be tempted to put production ahead of protection, and profit at the expense of safety, with occasional disastrous consequences. Therefore, many safety managers are sophisticated enough to avoid the logical error of referring to “safety as the top priority,” but instead refer to the need for safety as an enduring job requirement that accompanies all priorities.

An organization’s corporate culture must emphasize safety jointly with profit, controlling risk as a core value to help the bottom line, not to hinder profit. The best approach is a balanced allocation of resources where safety management is a core business function, closely intertwined with business objectives and not in competition with the profit aspects of the business. As shown in Figure 12-1, safety and profit should be perceived as inseparable, since an unsafe commercial operation will soon cease to be used by customers. Curiously, the picture depicts passengers with seatbelts unfastened, which further highlights the need for a company to enforce passenger safety requirements. This is one example of how enforcement of safety standards is vital to prevent personal injury.

FIGURE 12-1 The ultimate objective of SMS is maximizing safety efficiently. (*Source: FAA*)

In many chapters of this book, the reader has already been introduced to aviation SMS concepts. This chapter will bring together many of the previously discussed ideas as we formally introduce and explain the framework of SMS. We will discuss the history of SMS principles, the fundamental concepts, the tools and techniques used by aviation safety professionals, and the future of SMS in commercial aviation safety.

EVOLUTION OF SMS

It is clear that modern safety principles have significantly evolved in the years following World War II. Following the war, commercial aviation saw significant growth and so did the enabling technology with the introduction of the B-47, the jet engine, and swept back wing configuration. This *technical era* of aviation safety concentrated on the improvement of technical factors during the decades of the 1950s and 1960s.

In the 1970s, the Japanese gained world market share in the electronics and automobile industry using the “Total Quality Management” (TQM) concepts of quality experts, W. Edwards Deming and Joseph Juran, among others. This movement in Japan focused on improving the quality of manufactured products through teamwork and employee involvement. In the aviation world, the focus shifted to the *human era* by using such tools as Crew Resource Management (CRM) and Line-Oriented Flight Training (LOFT). As outlined by ICAO in the Safety Management Manual, the mid-1970s to the mid-1990s has been called the golden era of aviation human factors.

In the early 1990s, aviation safety thinking shifted its focus to the *organizational era*, where safety was viewed from a system perspective which included technical, human, and organizational factors. As previously discussed, Dr. James Reason’s so-called *Swiss Cheese Model* introduced the concept of the “organizational accident,” which is a breakdown of organizational processes resulting in an accident. Using quality-based employee involvement and cultural empowerment concepts employed by the Japanese and adopted by the International Organization for Standardization (ISO), aviation SMS theory has evolved into a worldwide movement which pays great safety dividends. It should not surprise the reader that SMS is closely tied to business efficiency concepts. After all, an accident is the ultimate expression of an inefficient process. Figure 12-2 illustrates the evolution of safety thinking from the technical era, into the human era, and now including the recent organizational era focus.

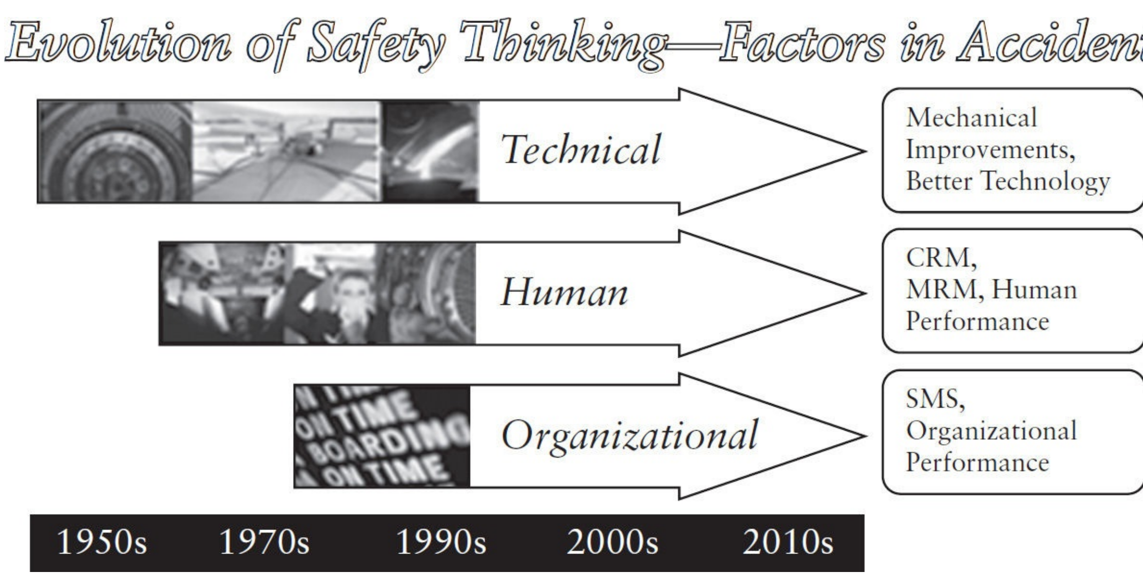

FIGURE 12-2 The roots of SMS can be traced to three overarching concepts. (*Source: FAA*)

As previously discussed in Chapter 5, ICAO is the United Nations

organization that issues international standards related to worldwide aviation. Since its foundation in 1944 at the Chicago Convention, ICAO has been in the forefront of airline safety matters, and its member States (191 countries) have agreed to abide by the ICAO annexes known as Standards and Recommended Practices (SARPs).

Annex 6 to the Chicago Convention deals with International Commercial Air Transport. Amendment 33 of Annex 6 sets the stage for international awareness and implementation of SMS by the world's airlines. It provides that ICAO member States shall require its operators to implement an SMS that as a minimum:

- Identifies safety hazards.
- Ensures that remedial action necessary to maintain an acceptable level of safety is implemented.
- Provides for continuous monitoring and regular assessment of the safety level achieved.
- Aims to make continuous improvement to the overall level of safety in the United States.

Safety Management System concepts began to influence government safety profoundly about 10 years ago in the United States. Early discussions made it clear that SMS would have to be adopted by both the regulator as well as the regulated and that there needed to be transparency for programs to succeed. This included a collaborative effort between the airline industry and the FAA to share data, analyze risk, and develop a plan of action for moving forward. Stolzer and Goglia (2015) tracked the timeline for SMS implementation in the United States. It was not until 2006 that ICAO established an amendment to Annex 6 which made it a requirement for ICAO members to develop and implement an SMS. At this time, the FAA began gearing up for the new requirement by developing an aviation rulemaking committee, piloting voluntary pilot projects, and creating informational material. The efforts targeted air carriers, repair stations, design and manufacturing firms, and airports. The objectives of the FAA's SMS pilot projects were threefold:

1. Develop SMS implementation strategies
2. Develop FAA oversight interfaces
3. Gain SMS experience for FAA and service providers

Major U.S. airlines started participating in these voluntary programs, as SMS implementation was also underway in the international airline community.

The crash of Colgan Air Flight 3407 near Buffalo, New York, on February 12, 2009 had a profound effect on commercial airline safety. By FAA Order 1110.152, the FAA established the SMS Aviation Rulemaking Committee (ARC), which was chartered to provide recommendations to the FAA on the development and implementation of SMS regulations and guidance.

Essentially, the SMS ARC recommended a detailed blueprint following ICAO international guidelines. The ARC recommended FAA SMS regulations and guidance be closely aligned and consistent with the same ICAO SMS framework of the 4 components and 12 elements discussed throughout this chapter.

In the wake of the Colgan crash, the U.S. Congress passed Public Law 111-216 which originally required a final FAA SMS airline rule by August 1, 2012. This requirement for all Part 121 air carriers in the United States was the first time that the FAA mandated the implementation of an SMS program. The final U.S. version of SMS is based upon the ICAO system and exhibits fundamental characteristics as recommended by the ARC. The features of the final rule regarding FAR Part 121 SMS include the following:

- Alignment with ICAO SMS framework and international acceptability.
- Phrased promulgation of regulations and implementation of SMS requirements by FAA.
- Scalability and flexibility of the regulations to accommodate a broad range of organizations.
- SMS processes should not change existing regulatory standards for FAR Part 121.
- Consistent with Public Law 111-216, the FAA recognition and implementation of existing voluntary safety systems as part of the airline's SMS such as the following:
    - Aviation Safety Action Program (ASAP)
    - Flight Operational Quality Assurance (FOQA) Program
    - Line Operations Safety Audit (LOSA)
    - Advanced Qualification Program (AQP)

In January 2015, a revised SMS Advisory Circular (120-92B) was published by the FAA which contains important information pertaining to all aviation sectors. The final airline SMS rule (14 CFR Part 5) requires airline operators

authorized to conduct operations under Part 121 to develop and implement an SMS within 3 years. By March 9, 2018, all U.S. Part 121 air carriers must have an SMS that meets 14 CFR Part 5 requirements. The corresponding SMS rule for Airports is in its final stages and should be released in the near future.

ICAO ANNEX 19: CONSOLIDATION OF SMS STANDARDS

In view of the increasing complexity and tighter interdependence among various aviation sectors, ICAO decided to consolidate all SMS standards into a new annex which allows a higher degree of integration of safety management functions.

Annex 19 is the first, new ICAO Annex in over 30 years and was developed in two phases. The first phase involved the organizing of existing safety management–related content, modifications to improve the language for clarity, and modifications to ensure standardization and harmonization of SMS information across the ICAO Annexes. It was adopted by the ICAO Council on February 25, 2013 and became applicable in November 2013. Recently a second phase resulted in Amendment 1 to Annex 19. It raises the components of SMS to the “Standard” level and also addresses the protection of safety data and information. This newly adopted Amendment to Annex 19 was effective in July 2016 and will become fully applicable in November 2019.

STRUCTURE OF SMS: FOUR COMPONENTS (Pillars of SMS)

In order to simplify and organize the best practices of managing safety, the Federal Aviation Administration (FAA) in the United States chose to formulate four large-scale components under which to organize concepts. Other countries follow a similar structure although some aviation organizations have different organizing plans. Regardless of SMS structures, the philosophies that guide the systems are all similar. SMS is as an organized approach to controlling risk from unintentional damage or harm, including the necessary organizational structures, accountabilities, policies, and procedures.

In the United States the SMS framework consists of 4 components (also known as pillars), and 12 elements within those components. The FAA provides guidance on these components as they are keys to implementing SMS. The four components of SMS are as follows:

1. *Safety policy*. Establishes senior management’s commitment to improve

safety continually; defines the methods, processes, and organizational structure needed to meet safety goals. This can be remembered via the expression *document it in writing*, referring to the need to have key aspects of a given SMS readily available to employees as a written reference.

2. *Safety Risk Management (SRM)*. Determines the need for, and adequacy of, new or revised risk controls based on the assessment of acceptable risk. This can be remembered via the expression *hunt the hazards, then assess and mitigate the risks*, referring to the fundamental need of having employees aggressively seek safety problems and having a means of effecting change to produce better conditions.
3. *Safety Assurance (SA)*. Evaluates the continued effectiveness of implemented risk control strategies, and supports the identification of new hazards. This can be remembered via the expression *measure and improve it*, referring to the need to use scientific principles to determine the effectiveness of the actual management change processes being used.
4. *Safety Promotion*. Includes training, communication, and other actions to create a positive safety culture within all levels of the workforce. This can be remembered via the expression *learn it and share it*, referring to the need to continuously learn about the SMS, about new and old hazards, and disseminating such life-saving information to all employees who can affect safety.

The FAA’s approach to organizing SMS by placing concepts into four components is illustrated in Figure 12-3. Note how the promotion component is shown to impact all three other components.

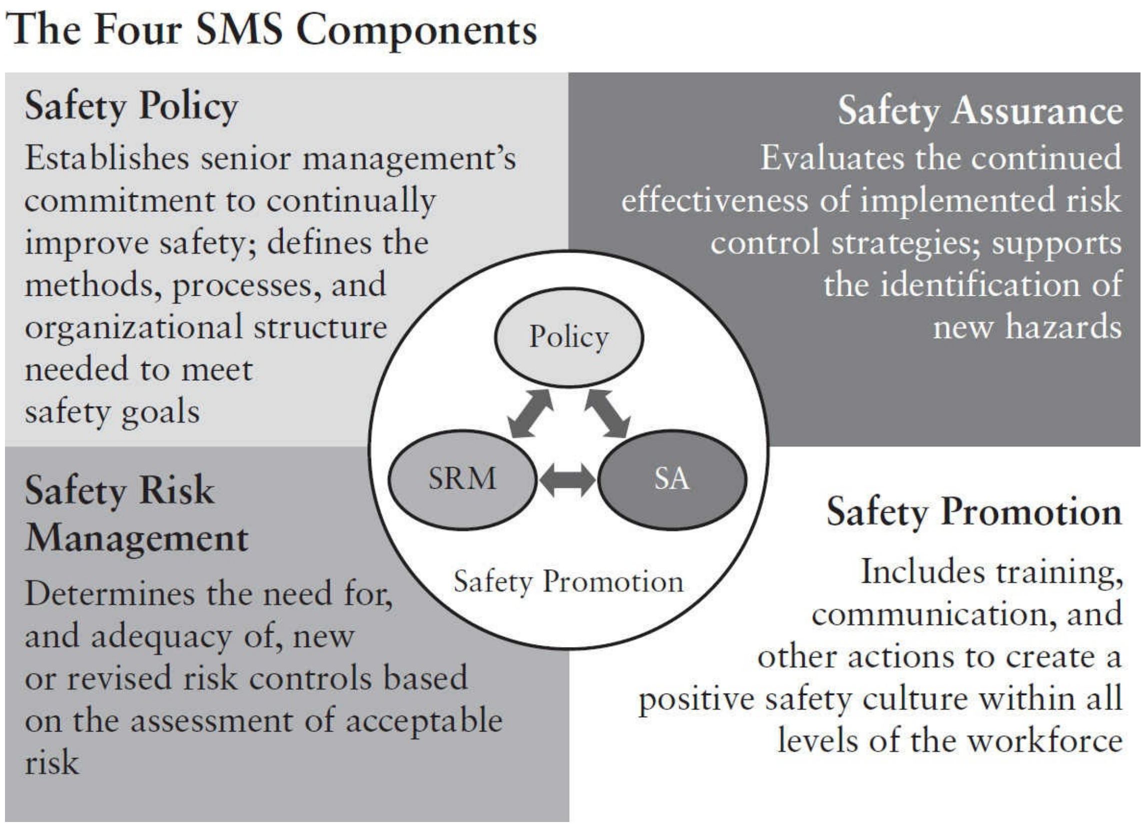

FIGURE 12-3 The organizing scheme for SMS. (*Source: FAA*)

COMPONENT #1: SAFETY POLICY

Safety policy encompasses the leadership of the *Accountable Executive* to provide clear safety objectives, methods, processes, and the organizational structure needed to meet safety goals. Safety promotion refers to the nonpunitive, positive safety culture (also known as a "Just Culture") which empowers all employees to have a role in safety. This is accomplished through comprehensive SMS training, communication, and awareness techniques.

It is appropriate that this element is placed first on the list since it sets the stage for the other elements to exist and reach full potential. The starting point for SMS Policy is identifying the "Accountable Executive" (AE), who is a single, identifiable person having final responsibility for the organization's SMS, including decisions regarding operations and everything that supports operations. The FAA has produced several flowcharts to help organizations determine who fills this important position. For purposes of this chapter, the reader can assume that the AE of a large airline will be the Chief Executive Officer (CEO), and of a small commercial aviation operation, the AE may be the owner.

That AE must then oversee how his or her “organization defines safety policy in accordance with international and national requirements and will sign the overall policy. It should reflect the organization’s commitment to safety, should include a clear statement about the provision of the necessary resources for the implementation of the safety policy, and should be communicated throughout the organization.” Identifying precisely who that AE is becomes critical because senior management is in control of the safe and efficient operations of the aviation organization. It is through management that employees are hired, trained, and dismissed when necessary. The safety policy should be developed by senior management and clearly communicated to all employees. It is extremely important that leadership be strong, demonstrable, and visible if the airline’s SMS program is to succeed.

Safety policy should also make clear that safety is the responsibility of all members of management, not just the safety department. The policy should clearly lay out who the safety manager is and how the company’s SMS shall be administered so that responsibility is widely distributed for safety. This will often take shape by using a *Safety Action Group (SAG)* and *Safety Review Board (SRB)* to assist management officials in accomplishing safety responsibilities. Under normal circumstances, the safety manager communicates to the AE through either the SAG or the SRB. The SRB is a very high level strategic direction group chaired by the AE, which includes senior line functional managers. Once strategic direction has been developed by the SRB, the members of the SAG are tasked with implementing the decisions at a tactical level. In this typical SMS organization, the Safety Manager serves as the secretary of the SAG to record its actions and keep score of corrective actions taken.

Safety policy should also ensure that an *Emergency Response Plan (ERP)* allows for a smooth transition from normal everyday processes to emergency operations and then back to normal conditions once the emergency has been managed. Airlines prepare an ERP document in writing to describe what actions should be taken following an accident and who is responsible for taking each action. An annual emergency response drill is usually required to ensure that the plan is adequate and that designated personnel are appropriately trained.

Lastly, careful documentation is an essential element of an SMS organization. Each AE should ensure that the safety manager has an SMS implementation plan that provides objectives, processes, and procedures and communicates who is accountable for what aspect of the plan. There also should be a manual that explains the whole SMS so that any employee can understand the operation.

COMPONENT #2: SAFETY RISK MANAGEMENT

COMPONENT #2: SAFETY RISK MANAGEMENT

The heart of any SMS organization is the interrelationship between safety risk management and safety assurance. Basically, the safety risk management process provides for the identification of hazards and assessment of risk. Once it is assessed, risk should be controlled (mitigated) to a level *as low as reasonably practicable (ALARP)*. At this point, the safety assurance process takes over to assure that the risk controls are effective using system safety and quality management concepts of monitoring and measurement.

Before a risk can be managed, a potential hazardous condition must be identified. It is easy to confuse the concepts of hazard or risk. A *hazard* is "a condition or activity with the *potential* to cause death, injuries to personnel, damage to equipment or structures, loss of material, harm to the environment or reduction of the ability to perform a prescribed function" (*Source: ICAO Safety Management Manual, 3rd ed., Section 2.13.2*). An example of a hazard is a leak in the hydraulic line of an aircraft braking system, but because it is not a risk in and of itself, the leak does not let us know how it impacts safety.

A risk is the assessment, expressed in terms of predicted probability and severity, of the consequences of a hazard taking as reference the worst credible effect. Thus, risk can be expressed in a formula as: $R = P \times S$, where

- R is the expected risk (loss) per unit of time or activity
- P is the probability that a given hazard may materialize (likelihood of a loss event per unit of time or activity)
- S is the severity of consequences (effects) that the materialized hazard can generate (loss per event)

So, returning to the previous example:

- A leak in the hydraulic line of an aircraft braking system is a hazard.
- The potential for running off the runway because the pilot might not be able to stop the aircraft on landing using brakes is one of the consequences of the hazard; however,
- The assessment of the consequences of literally running off the runway expressed in terms of *probability (P)* and *severity (S)* is the *safety risk (R)*.

Stated another way for clarification, in the equation $R = P \text{ x } S$:

- P is the probability that the aircraft would run off the runway given that its

stopping capability is impaired.

- *S* is the severity of the above event which could vary from no aircraft damage or injuries (near miss) to total destruction, or both (depending on variables such as the aircraft speed and runway remaining when the braking fault is noticed, availability of other means of stopping, etc.).

Now that you can differentiate between a hazard and risk, it will make understanding the importance of the elements in the second component, safety risk management, easier. Analyzing a large volume of safety data from flight operations and determining risks are only one part of the equation. The information we gather is an integral component in creating, implementing, and validating the effectiveness of risk mitigation in an SMS. For this reason, the second component of SMS incorporates both hazard identification and risk assessment mitigation.

Safety risk management begins with a clear understanding of an organization's functional systems, which are analyzed by experienced operational and technical personnel to detect the presence of hazards. Under SMS, each organization should create and maintain a formal process that ensures that operational hazards are identified. Such a process should be based on a combination of reactive, proactive, and predictive methods of safety data collection. How hazards are identified will depend on the resources, culture, and complexity of the organization.

After the safety hazards have been identified, they must be analyzed to determine their consequences to the organization. This step entails creating and maintaining a formal process that ensures analysis, assessment, and control of the safety risks in operations. The conventional method to analyze risk is to break it into two components, the probability of occurrence and the severity of the event should it occur, as previously described. Typically, one tool often used is called a "risk tolerability matrix," which visually displays a risk to determine if it is unacceptable or needs further mitigation to reach the ALARP or acceptable region. ICAO illustrates this risk tolerability as an inverted triangle as shown in Figure 12-4. Note the coding of the risk matrix:

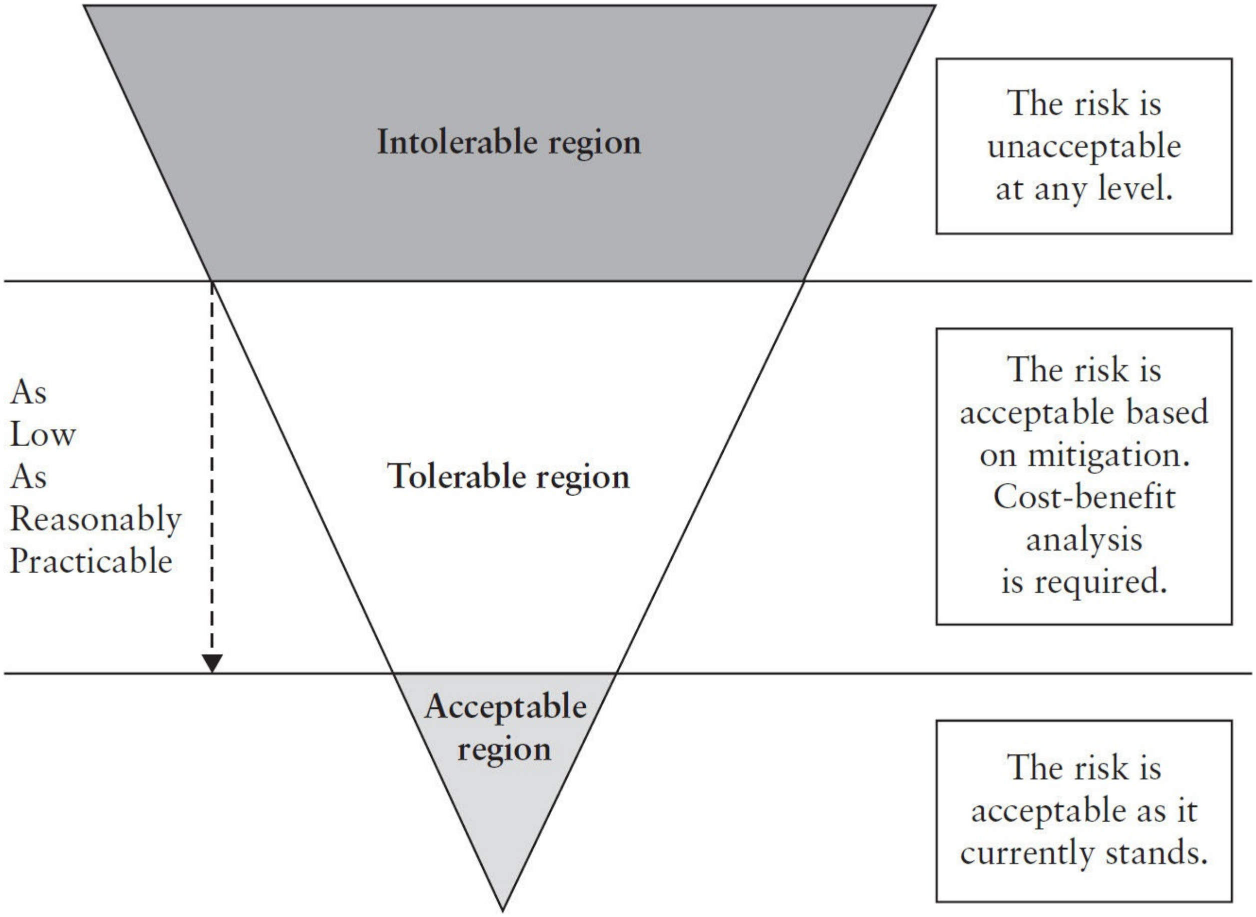

FIGURE 12-4 Safety risk management—tolerability matrix. (*Source: ICAO Safety Management Manual, 3rd ed., Section 2.14.11*)

Dark gray—unacceptable risk (intolerable)
White—acceptable with mitigation (tolerable)
Light gray—acceptable region

To conduct a safety risk assessment, it is very helpful to plot it visually to clearly see the relationship between severity of consequences and likelihood of occurrence. The classic ICAO/FAA example of using a chart is provided in Figure 12-5.

Risk Likelihood	Risk Severity				
	Catastrophic	Hazardous	Major	Minor	Negligible
Frequent	High	High	High	Medium	Medium
Occasional	High	High	Medium	Medium	Medium
Remote	High	Medium	Medium	Medium	Low
Improbable	Medium	Medium	Medium	Low	Low
Extremely Improbable	Low	Low	Low	Low	Low

FIGURE 12-5 Sample severity and likelihood criteria. (*Source: FAA Advisory Circular 120-92B*)

Safety Management System processes that use such a risk matrix require the development of criteria that explain each classification of severity and likelihood appropriate for the organization's type of operations and their operational scenarios. For example, one organization operating smaller and less complex equipment may depict severity in terms of the dollar value of potential damage that is quite different from another organization utilizing very expensive equipment. Such risk assessments are often a combination of professional experience and expert judgment, including input from data collection tools.

The purpose of risk mitigation is to control hazards by either eliminating them altogether or by reducing the severity or likelihood of the hazard to an acceptable level. We must look for the "weak signals," which are early indicators of problems that many may not perceive as a danger. The order of precedence (hierarchy) for these controls is well established, and they are listed below in rank order from most effective to least effective (Stolzer & Goglia, 2015, p. 171):

1. *Elimination of the hazard*. The most effective is the engineering control strategy which eliminates the safety risk completely. An example would be providing interlocks to prevent thrust reverser activation in flight. Since this is a firm control solution, it is sometimes known as a "hard" control

strategy.

2. *Reduction of the hazard level*. Reduction of the probability or severity of the event reduces its overall impact, perhaps moving its classification from unacceptable to acceptable on the risk assessment matrix. For example, the probability of a ramp agent being hit by a baggage cart tug can be reduced by requiring ramp personnel to wear reflective vests and the severity of being hit by a tug can be reduced by limiting the driving speed of tugs.
3. *Employment of safety devices*. This control method is mechanical in nature (safety guards, rails, etc.) and often prevents exposure to potential hazards.
4. *Warnings and alert methods*. These could be visual (warning light) or audible, such as an aircraft stall or landing gear warning horn. A weakness of such methods is that the warnings and alerts in and of themselves do not prevent damage or injury unless humans respond correctly.
5. *Safety procedures*. These are known as administrative control strategies, and thus are considered a "soft" control measure. Training and regulations can be put into place, but human error can negate this type of control.

Control strategies, techniques, and protective equipment impact the risk equation ($R = P \times S$) in the following ways:

- *Design and engineering* will aim to reduce/eliminate the hazard and works on the probability (P) side of the risk equation, which subsequently reduces/eliminates the severity (S).
- *Safety devices*, which can be active or passive, reduce risk in a similar way to *design and engineering* but are considered less effective. They can be used to reduce severity and/or probability. Active safety devices require human action and are not as effective as passive devices. Examples include seating heights and windshields that provide increased visibility for pilots or collision avoidance systems. Passive devices require no human action to activate. They do not perform active monitoring but are always present. Examples include guardrails and safety nets.
- *Warning devices* increase awareness of the hazards, and hence, reduce the probability of being impacted by hazards. Should the warning be ignored, the full extent of severity will be felt.
- *Procedures and training* are mainly intended to reduce probability (P) but can also reduce severity(ies) as in emergency evacuation drills.
- *Personal protective equipment* (PPE) serves to reduce the severity (S) from a

materialized hazard. PPE should be considered the last line of defense, as it requires human input to be worn correctly, and even if worn correctly, it can be uncomfortable and cumbersome to wear.

To wrap up some of the most important concepts about safety risk management, let us use the example of a voluntary reporting system for aviation maintenance technicians performing routine maintenance to an Airbus A320. An employee reported that the shift change process does not ensure that a work task has proper continuity between technicians. A proper SMS will institutionalize a routine method for assessing the risk associated with such a hazard, would implement controls for the risk, and then would provide a means to measure the control in the future to assess adequacy.

Incident and Accident Investigation

Some progressive companies investigate all unintended events, irrespective of whether these events led to injuries, illnesses, property damage, or equipment damage. This is done so that hazards are detected before they cause a significant impact on safety. Unfortunately there are still situations when safety is impacted, sometimes severely. This impact can range from incidents to accidents. An important component of the safety effort at any organization is an incident and accident investigation system. By investigating accidents, organizations learn how to prevent future accidents. Most companies, however, require some criteria to be met before an investigation is triggered. Investigations are initiated, for example, if accidents

- Require reporting on the OSHA 300 log
- Generate workers' compensation claims
- Cause personal injuries or lost workdays
- Meet NTSB definitions of accidents/incidents
- Result in an environmental spill
- Cause property and/or equipment damage over a certain dollar value

Once an investigation is triggered, the processes used, whether they are FAA/NTSB, OSHA, or EPA related, are very similar. A formal notification system should be in place to provide timely notice of such events to the safety department. A typical investigation process is now described.

Once the safety department is informed of an event, an immediate determination is made about whether the event meets the company's criteria for

determination is made about whether the event meets the company's criteria for an investigation. When an investigation begins, depending on the circumstances, one or more individuals may be assigned to conduct the investigation, especially when it is clear that there may be more than one operating department involved, such as for incidents occurring during pushback where a flight crew, ramp agents, and perhaps ramp tower personnel may all be involved.

The manner in which the investigation is conducted is a function of the type of event and the circumstances under which it occurred. Typically, all key personnel involved in an incident or accident are asked to submit written statements describing the facts and circumstances as they saw them. In addition, provisions are made immediately for conducting interviews with the key individuals involved in the incident or accident. These interviews can be done in person or over the telephone, depending on the specific circumstances. In person interviews are preferred. Similarly, interviews can be done individually or with a part or all of an entire crew. The people being interviewed are told that the purpose of the interview is safety only, that the information will not be used for any disciplinary or other purpose. Accounts will remain confidential to the extent permitted by law. Information learned from these interviews, along with written statements, forms an important element of these safety investigations.

In addition to the interviews and personnel statements, other records and documents may be obtained and reviewed. Such material might include training records, training manuals and syllabi, aircraft and procedures manuals, information bulletins, and similar material. Another important source of information is the aircraft flight data recorder, which is read out as part of the investigation of many inflight events. Other relevant information is identified and obtained as necessary, including accident reports, technical reports, and any other documentation that may contain information relevant to the incident or that can provide useful information for formulating recommended practices and corrective actions.

Following the collection of basic information, the investigator assembles and issues an accident report. These are brief, synoptic reports that describe the basic facts and circumstances of the event under investigation, including a history of the event, a summary of damage and injuries, an analysis, a list of findings, and, most importantly, recommendations for corrective or future preventive action. Also included is a brief summary of safety actions taken—operating departments are not required to wait for a formal recommendation from the safety department prior to initiating corrective or preventive action.

Findings from safety investigations are derived from the facts and circumstances associated with the event and are based on the investigator's

analysis. There is no effort to determine a cause or probable cause of an event. Findings are essentially a list of objective factors related to the event under investigation.

The recommendation process is probably the most important part of this safety investigation program, and it is important to understand how it is handled.

The accident investigation process described applies to investigations of minor accidents. In the case of a major accident (hull loss, occupational death, or a major environmental spill), coordination will be required with external agencies (NTSB, FAA, OSHA, EPA). (See Chapter 6.) For example, in the event of an aircraft crash, it is important that an airline has a detailed ERP that contains, among other things, detailed plans for an airline go-team who will participate in the accident investigation. The go-team should be headed by a senior manager, who serves as the primary coordinator for all company activities related to an accident investigation. Appropriate technical personnel are designated as potential members of a go-team, the actual makeup of which is determined on the basis of known facts at the time of notification, most importantly, aircraft type and location. With regard to the latter, for any accident occurring outside of U.S. airspace, the company go-team reports to the U.S. accredited representative, in full accordance with ICAO Annex 13.

To support the go-team, all necessary equipment and supplies, such as PPE, communications gear, and other material that may be necessary to conduct a major accident investigation, must be ready for instant shipment to the scene of an accident. All members of the go-team should be formally trained in accident investigation and must have the OSHA-required blood-borne pathogen training. The go-team roster should also identify other personnel who are tasked with providing administrative support to its technical members.

The ERP specifies the staffing of a command post by designated personnel from the affected airline. These people are responsible for the coordination of all activities related to the accident investigation, including the assembly of records, manuals, bulletins, and other necessary materials. Oversight and leadership of the entire effort should be under the direction of senior management, including the corporate safety officer. An annual emergency response drill is required to ensure that the plan is adequate and that the designated personnel are appropriately trained.

Although absolutely necessary, an ERP and associated elements of the safety function are quite obviously something that no airline wants to activate for real. To meet this challenge, every airline company must have some form of independent, proactive accident prevention effort. The best means to accomplish this is to seek to identify hazards and risks consistently and then to eliminate

these risks through accident prevention measures using SMS concepts.

On a final note, virtually all operational incidents will require a certain level of technical investigation and analysis to fully understand and identify the underlying cause factors. Within the airline corporate structure, investigative responsibility for flight safety incidents must be clearly assigned. Similarly, professional investigative methods must be consistently employed in the technical area. Use of investigative tools such as the digital flight data recorder (DFDR) requires a consistent objective and confidential method of analysis, often under the supervision of the NTSB if the Board assumes jurisdiction of the accident or incident. Also, since analysis methods require complex transcription methods, it is likely that DFDR analysis will occur at the maintenance or engineering department. DFDR contents must always be maintained in a strict confidential status with operational DFDR analysis performed by personnel familiar with current operational procedures.

ROLE OF UNIONS

Quite a few airline pilot unions exist, such as the Southwest Airlines Pilots' Association (SWAPA), with more than 8,000 members, or the Allied Pilots Association affiliated with American Airlines, which has around 15,000 members. The largest is the International Federation of Air Line Pilots (IFALPA), which is a labor union founded in 1948, headquartered in Montreal, Canada, and accounts for over 100,000 members in over 100 countries. Air safety is a primary responsibility of every airline pilot. As the oldest and largest airline pilots' union, the main role of IFALPA's air safety structure is to provide channels of communication for line pilots to report air safety problems. The U.S. component of IFALPA is the Air Line Pilots Association (ALPA).

An additional role is to stimulate safety awareness among individual pilots to enable flight crewmembers to be constructive critics of the airspace system. Finally, the air safety structure helps investigate airline accidents. Over the years, ALPA's air safety structure has contributed significantly to air safety. Airline pilot unions have trained safety volunteers and led industry projects on aircraft wiring safety, human performance, and nonpunitive corporate cultures, among many other hot topics.

Focusing on ALPA as an example, the basic unit of the union is the local council—the pilots of a single airline at a particular operating base. Each local council normally has an air safety committee, which processes local air safety problems and is headed by the local council air safety chairperson (LASC), who is appointed to a 2-year term by the local executive council (LEC) or the LEC

chairperson.

An airline’s central air safety committee is then made up of all of the LASCs from that airline’s various councils. The central air safety chairperson (CASC), appointed to a 2-year term by the master executive council (MEC) or MEC chairperson, presides over the committee, which handles unresolved problems from the local councils and those broader in scope than local issues.

The national safety structure of the Air Line Pilots Association is composed of five management groups, headed up by Executive Air Safety Chairman, in these specific safety areas:

- Aircraft Design and Operations
- Airport and Ground Environment
- Air Traffic Services
- Human Factors and Training Group
- Accident Analysis

The Accident Investigation Board of the Air Line Pilots Association oversees investigation of accidents involving the air carriers they represent. The board coordinates ALPA’s participation in accident or incident investigations conducted by the NTSB or the FAA and ensures that the appropriate ALPA subgroup determines the significant factors in each air carrier accident. ALPA also maintains a worldwide accident/incident hotline for its pilots to call for help if involved in an aircraft critical safety event. If deemed necessary, ALPA will also employ its Critical Incident Response Program (CIRP), which counts on trained counselors who work to mitigate the psychological effect of an accident before harmful stress occurs.

More specific to SMS, since 2008, ALPA has been a leader in supporting SMS principles as set forth in the ICAO Safety Management Manual. The ALPA policy statement is that they support SMS when it is developed and implemented in accordance with the following:

- A documented, clearly defined commitment to the SMS from the CEO—a written SMS policy, signed by the CEO, which recognizes the business benefit of asset preservation and mishap prevention. The policy must show commitment to continuous improvement in the level of safety, management of risk, and creation of a strong safety culture.
- Documented lines of safety accountability.

- Active involvement of the affected employees in a nonpunitive reporting system and a commitment to a “just” safety culture.
- A documented, robust Safety Risk Management (SRM) program. The SRM program requires the participation of labor organization(s) as the representative of their employee groups in both the identification of hazards and in the development of risk mitigation strategies.
- A documented process for collecting and analyzing safety data and implementing corrective action plans.
- A documented method for continuous improvement of the SMS.

(*Source: ALPA Administrative Manual, Section 80, Part 1, page 18, www.alpa.org*)

Working to maintain the highest levels of airline safety is an enormous challenge. The depth and breadth of ALPA’s air safety structure, and the critical role it plays in meeting that challenge, are unique in the air transportation industry.

Pilot unions are just one of several, powerful and resource-rich labor organizations that can be used as an extension of an airline’s SMS. Aviation maintenance technicians often work as part of labor unions, as with the International Association of Machinists and Aerospace Workers (IAMAW), which represent over 600,000 workers in more than 200 industries. The IAMAW’s Safety & Health Department has promoted safety in topics such as hazardous material, occupational health, and as proponents of the Ground Operations Safety Action Program. Safety leaders in the Association of Flight Attendants (AFA) have been strong champions of finding better ways of managing crewmember fatigue, investigating aircraft cabin air quality, fighting the spread of communicable diseases, and passenger security screening. After all, as shown in Figure 12-6, flight attendants often have the best perspective of issues affecting passenger safety on a routine basis, such as turbulence and health ailments. AFA is the world’s largest labor union for flight attendants and represents nearly 50,000 cabin crewmembers at 18 airlines.

FIGURE 12-6 Flight attendant performing a pre-departure passenger safety briefing. (*Source: Wikimedia Commons*)

Whether they are safety leaders in pilot unions, maintenance technician unions, flight attendant unions, or other organized labor groups, individuals who perform safety work for labor unions are often highly motivated to find solutions and can contribute greatly to an airline's SMS.

COMPONENT #3: SAFETY ASSURANCE

Once the risk assessment and controls are in place and "ALARP" has been declared, the SMS process shifts to the safety assurance side of the ledger to provide feedback on how the safety risk management process is performing. By leveraging efficiencies gained in SMS data and combining cross-functional trends into a centralized safety database, safety professionals can analyze what is happening over time better and target their mitigations strategically. If performing well, the safety assurance process provides positive reinforcement that risks are properly managed. However, new hazards may inadvertently be introduced into an SMS whenever a change occurs.

There are numerous sad examples from safety history that demonstrate how the best of intentions for risk mitigation end up introducing new hazards into

operations. One example that some readers may be familiar with is how the introduction of air bags in cars initially caused serious injury or death to small people when the air bags activated for collisions. An aviation example of an unintended consequence from the actions taken to promote safety is the incredible precision available in modern flight deck avionics instrumentation. Such precision is usually quite helpful to promoting safety, but the Gol Airlines and Embraer jet midair collision over Brazil in 2011 pointed out the midair risk of two aircraft flying at the exact same altitude over the same point in time. Had the altimeter or navigation systems been less precise the accident may not have occurred. Also, a mature risk mitigation process which is ostensibly under control may become unsafe when faced with changes to the system. Furthermore, a new operational procedure or system change needs to be verified by the safety risk management process to see whether it has an impact on other processes. One of the more important aspects of safety assurance is an effective formal change management system.

As previously mentioned, a key aspect of change management is being able to measure what effect we have had with actions taken to sustain or enhance safety. It has been stated as a matter of truth that the only thing constant in aviation is that things will surely change. A formal process for managing these frequent changes is necessary for an efficient airline SMS program. Every airline should create and maintain a formal process that identifies changes that are occurring within the company that may impact previously developed processes. The formal change management system should consider how critical the system is to the airline, and whether the change introduces new, unforeseen hazards or risks.

To determine whether change is occurring, and to detect whether it is happening to the benefit or detriment of risk management, safety performance monitoring and measurement is a critical part of an efficient SMS safety assurance process. After the hazards are identified and the risks are assessed, properly mitigated, and controlled, operational performance must be monitored and measured in order to ensure optimum effectiveness of the SMS. This is an internal process of the SMS team, focusing on data and information regarding the performance of the safety system. Finally, the last element of Safety Assurance is the continuous improvement of the SMS operation. Quality feedback monitoring processes are strongly recommended by both ICAO and the FAA to enhance the entire operation of the system.

Safety Performance Indicators

It is tricky to measure how well SMS is working because health does not

necessarily correlate to a reduction in the number of accidents. As a result, a key component of the SMS model that was adopted from the business realm is the use of performance indicators to assess the effectiveness of safety programs. Under SMS these are called *safety performance indicators (SPIs)*. *ICAO Annex 19* defines an SPI as "a data based safety parameter used for monitoring and assessing safety performance." It measures whether or not a system is operating in accordance with the goals of the safety program as opposed to simply meeting regulatory requirements. Using SPIs represent a shift from traditional data collection and analysis methods to the development of mechanisms that continuously monitor safety risks, detect emerging safety risks, and determine any necessary corrective actions.

Unfortunately, the ICAO Safety Management Manual only provides the definition and guidance on the use of SPIs with a few generic examples. Consequently, individual organizations must develop their own meaningful measurements. There are several traits that determine a well-crafted SPI. An SPI, if properly created, for the organization:

- Gives direct and unambiguous information on the specific item being measured.
- Draws attention to dangerous trends and events.
- Adds value to the safety performance.
- Analyzes both internal and external factors that can impact safety controls.
- Aligns with an organization's safety targets.
- Measures what they are intended to measure.
- Is responsive to changes and statistically significant.

The challenge of creating SPIs lies in narrowing the focus of a specific measurement. Organizations should focus on selecting indicators that can impact future operations from the unwanted events that they are trying to eliminate. Each SPI should be created for a different purpose, and the more critical the issue, the narrower the focus should be.

Every organization has the flexibility to create its own SPIs and should do so according to its needs and operations, although some SPIs may be predetermined and required by a regulatory authority as a mandatory measurement. Flexibility is important because there are no predefined SPIs for specific aeronautical services. This characteristic enables organizations to develop the cornerstone for their performance-based oversight. Since ICAO's verbiage lacks advice on

creating SPIs, IATA is currently developing material to assist operators in this task.

To provide an SPI example, Figure 12-7 shows a commercial jet operating in the vicinity of thunderstorms, which of course could produce inflight turbulence. Such operations are common in commercial aviation and an associated safety performance indicator chosen by the airline may depend on the culture and operational specifics for the organization. For example, one air carrier may choose to create an SPI that tracks the very few passenger injuries that occur due to turbulence, while another one may use an SPI that measures a wider number of incidents by tracking how many flight attendant injuries result from encounters with inflight turbulence. Another operator may prefer to create an even wider SPI that measures the number of unforecast turbulence encounters as reported by pilots, whereas another airline may prefer an SPI that measures an even larger population of events, such as moderate and severe turbulence encounters as measured through a flight data monitoring program.

FIGURE 12-7 A variety of SPIs could be created to manage the common problem of inflight turbulence. (*Source: Wikimedia Commons*)

Creating SPIs paves the way for setting safety alert levels. Organizations should select *statistical process control* limits of the maximum number of safety events that can occur for them to still be operating within the acceptable range of safety. Statistical analysis of data from SPIs enables organizations to pick a quantifiable threshold for the alert zone. When the alert levels are reached, then there should be further investigations or a causal analysis combined with a plan that uses SMS tools to bring performance back to an acceptable safety level. Although alert levels are somewhat subjective, they can be very useful to help determine between significant and insignificant trends.

As the aviation industry shifts to using SPIs, organizations will benefit from the conclusions they can derive from the metrics. This data will provide meaningful information that cannot be manipulated and that truly reflects operational trends. Additionally, the flexibility of customizing SPIs allows each organization to focus on its own operational context and challenges.

Commercial aviation can use numerous data acquisition approaches for monitoring and measuring safety performance as part of an SMS, which include the following:

1. *Continuous monitoring* comes from a variety of sources, but especially from line managers who are the technical experts in any organization.
2. *Internal audits* are conducted by operating departments of the organization.
3. *Internal evaluation audits* are conducted by people who are functionally independent of the process being evaluated.
4. *External audits* are conducted by the FAA or by third-party organizations using tools that conform to standards agreed to by trade organizations.
5. *Investigations* of accidents, incidents, or other safety-related events are conducted in a nonpunitive fashion to determine why the safety problem happened.
6. An *employee reporting system* such as ASAP or other voluntary method is utilized.
7. *Analysis of data* is conducted, especially to identify root causes of any nonconformance and to identify potential new hazards.
8. *System assessment* is conducted to determine the safety performance and effectiveness of risk controls.

AUDITS AND INSPECTIONS

The mention of audits and inspections bears special discussion, because as noted above, a primary element of safety assurance is the need to continuously improve a company's SMS. Rather than maintain the safety status quo, the SMS process seeks continuous improvement using tools such as internal evaluations and independent audits to obtain timely feedback information. Each SMS should create and maintain a formal process for detecting the reasons for substandard performance of the SMS and also to determining how that substandard performance impacts operations, in hopes of either eliminating the reasons altogether or at least making them less damaging. Continuous improvement can be greatly enhanced by a strong safety culture and committed management officials. Proactive evaluation of facilities, equipment and procedures, and vigilance are a must for SMS effectiveness. Continuous improvement of the SMS is a never ending goal and two overall processes can be used toward that end:

- *Preventative/corrective action* assignments must be tracked and managed. This is an active process requiring routine follow-up and continuous assessment.
- *Top management review* should be regularly conducted by the SMS Accountable Executive and other safety boards and committees at all levels of management. This review should include the inputs and outputs of SRM and the lessons learned from the safety assurance process.

Analyzing and addressing hazards after they have materialized (caused accidents and injuries) are commonly referred to as a reactive approach to safety. The preferred proactive approach to safety requires that hazards and hazardous conditions be identified before they cause accidents and injuries. Using modern SMS strategies, the proactive approach to safety does not require a triggering event to take place. Instead, the proactive method aggressively seeks safety information to identify potential future problems. The ICAO Safety Management Manual illustrates these three safety management strategies detailed below.

One way of accomplishing safety assurance in an SMS environment is through the comprehensive audit process. The words "audit" and "inspection" are often used interchangeably with some confusion about their definitions. Most schools of thought (including the authors of this text), however, consider an audit to be more comprehensive and have a greater scope of work than an inspection. While inspections usually identify workplace hazards, audits are designed to evaluate programs and management issues that have resulted, or could result, in workplace hazards. Safety audits are an integral part of a safety

program, and in addition to uncovering hazards, audits reveal the level of compliance with regulatory standards as well as measure the effectiveness of the safety program. Some of the common approaches to auditing an airline or airport facility are as follows:

- *Comprehensive audits*. These are extensive, detailed safety inspections/surveys (site conditions and programs) of the entire organization (an air carrier), a facility within an organization (an air carrier hub or maintenance facility), or an operation within a facility (fuel handling at the ramp). These audits are usually conducted on an annual basis by a team of safety professionals from within and outside the organization, facility, or site. They are usually led by the company safety director or the divisional or site safety manager. This type of audit results in a formal written report of findings and recommendations and usually requires a response within an agreed time frame. For example, Figure 12-8 shows a technician using a ball rotary file to modify a scallop ring so heat expansion will not cause cracking. An audit of an engine shop such as the one shown in the figure can help catch factors that lead to a deviation from established procedures and then produce recommendations to prevent a recurrence.

FIGURE 12-8 The comprehensive audit of an engine shop can produce recommendations through observation. (*Source: Wikimedia Commons*)

- *Self-audits*. These are informal daily, weekly, or monthly audits that resemble inspections and form the crux of the internal inspection program (IEP). The frequency of checks depends on the operation being assessed. For example, certain areas of airports have to be checked several times per day, whereas some operations in a hangar or on the ramp may only require one inspection each day. These audits are conducted by on-site line management at a given facility and usually result in a checklist of items that either are in acceptable condition or need fixing. No reports are normally generated as part of these audits. One of the functions of the Director of Safety is to help set up and provide expertise to local internal inspection teams.
- *Status audits*. These audits are intended to determine the status of compliance at the time of observation. These are usually subject-oriented audits and are conducted in areas of high risk and/or areas of known or perceived concern. Evaluating a welding operation is an example of a status audit. These audits may generate reports if the findings are serious enough to require management's attention.

COMPONENT #4: SAFETY PROMOTION

An integral part of a strong SMS culture is safety promotion. If the attitude of employees is that the program is only for compliance with regulations, then regard for safety and the SMS will not permeate through all aspects of daily operations. For this reason, the final component of SMS calls for the airline to continuously promote safety as a core value of the organization.

The building blocks of a good program are depicted in Figure 12-9, and training programs should be tailored to an employee's job function in the organization. The left-most block in the figure describes how operational personnel should understand the airline's safety policy and have at least a functional understanding of how SMS operates. Added to that, the center block in the figure portrays how managers and supervisors must also have a more in-depth understanding of the safety processes used by their airline to include hazards identification and change management to address the risk associated with such hazards. Lastly, the right-most block of the figure depicts how senior managers must go beyond SMS fundamentals to ensure that organizational standards and regulations are observed.

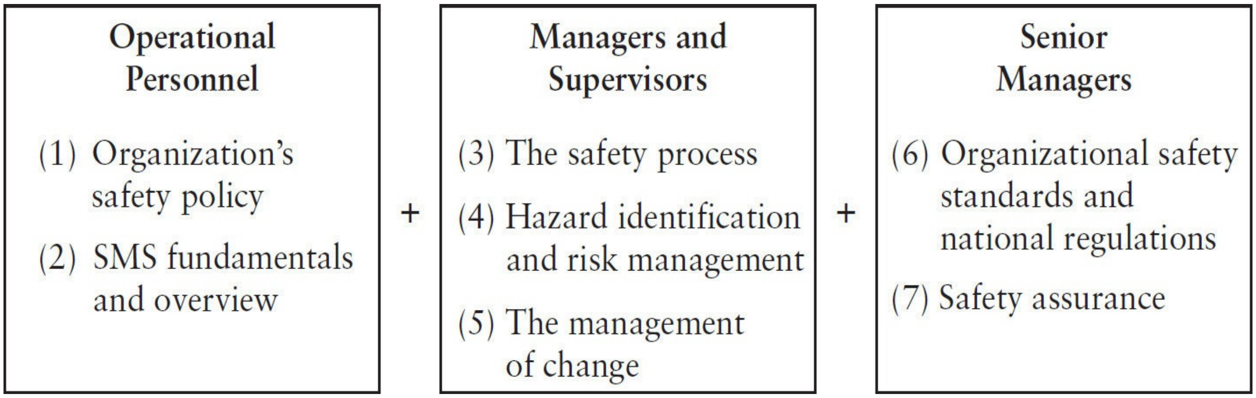

FIGURE 12-9 Safety training and education fundamentals. (*Source: ICAO*)

Safety Training and Education

Within the safety promotion component of SMS, there needs to be a formal and recurrent process for training employees in safety. This requires creating and maintaining a *safety training program* that ensures personnel are trained and competent to perform SMS duties. The scope of the safety training should be appropriate to each individual's role in the SMS, meaning that the training programs should be customized to the different roles played by employee groups in the organization. An aviation maintenance technician working in a hangar and a customer service agent staffing a check-in counter at the terminal will naturally have different impacts on the SMS of their airline and need to be trained on how their role impacts the safety of the operation. It is important to note that the AE should also receive special SMS training regarding roles and responsibilities, including an understanding of the SMS and its relationship to the organization's overall business strategy.

Safety training is most effective when it is integrated into a company's performance and job practice requirements. The following important, yet common, guidelines should be noted and adhered to by organizations:

- The company's policy should clearly state the company's commitment to safety.
- The training should be conducted on paid work time.
- Training must be in the language that the employee understands and should be delivered at an appropriate pace and comprehension level.
- Employees and management should be involved in developing training programs.
- Training should be conducted based on identified needs.

- Training should have clearly defined goals.
- Training should follow good teaching pedagogues and should incorporate the following basic principles:
  - The attendee must understand the purpose of the instruction.
  - The information should be organized to maximize understanding.
  - “Hands-on” experiences should be embedded whenever possible.
  - The training should be designed for different learning styles, such as written instruction, audiovisual instruction, hands-on exercises, and group learning assignments. Straight lectures should be no more than 20 minutes long.
  - Key concepts should be repeated for reinforcement.
- There should be an evaluation component to training. Both the attendees and the training itself should be evaluated. Attendees can be evaluated through tests, quizzes, assignments, *etc.* Course evaluation questionnaires/surveys can be used to evaluate course content and its ability to achieve the stated goals.
- All employee training records should be documented and maintained. This will help ensure that every employee who needs training receives it, that refresher courses are provided when needed, that documentation is available when required to prove that training was conducted (a regulatory requirement in some cases), and that the training was appropriate. Documentation should include the following:
  - The name and signature of the trained employee
  - The training date
  - The topic, including a brief lesson plan
  - Evidence of the employee’s successful completion
  - The name and signature of the trainer

Safety Communication

A large part of safety promotion involves the critical need for communication. A robust SMS culture encourages a learning environment where employees communicate openly up and down the management chain without fear of reprisal. Each organization should create and maintain a formal means for safety communication that ensures that all personnel are fully aware of the SMS, conveys information that is critical to safety, explains why particular safety actions are taken, and details why safety procedures are introduced or changed. This guidance means that employees should have easy access to their

organization’s SMS manual and associated safety process and procedures. Communication processes should also include airports and other providers of service to the airline.

A healthy SMS may also feature safety newsletters, notices, and bulletins, plus the use of Web sites or e-mail to keep employees in the loop regarding safety issues and resolutions. Safety publications are an important component of a safety program. Most airlines publish regular internal safety documents to maintain high individual awareness of safety and risk management. Videos are also used to disseminate safety information to all employees. Communication and education are critical elements of any proactive safety program; there must be an effective mechanism in place to ensure the flow of critical safety information within the company.

In conjunction with the safety risk management process, the communication of pertinent information necessary for reduction of the risk must be provided to the safety user. Depending on the type of risk involved, the user may be a pilot, flight attendant, aviation maintenance technician, or related support person. Recurring material failure causes, such as fuel pump failures, would probably only be distributed to technical services or the maintenance department, while human factors issues would be best communicated to all employee groups for example.

Figure 12-10 shows a pair of aviation maintenance technicians working under the cowling of a Boeing 737-800 power plant. A safety manager viewing such an operation may contemplate what communication processes are used to relay important safety information to them and whether the corporate culture he or she is helping to create is one that encourages such technicians to freely report the hazards that they encounter.

FIGURE 12-10 Empowering technicians to report hazards without fear of reprisals is a key aspect of a healthy SMS. (*Source: Wikimedia Commons*)

Communication takes on many forms in an SMS. The airline safety, maintenance, and flight operations organizations are often mistakenly viewed as separate entities with little or no shared mutual interests, when in actuality, the three organizations are closely aligned by complex relationships as will be shown in the ASRS examples later in this chapter. While the maintenance department provides virtually all the technological expertise necessary to maintain the aircraft fleet, the pilots and flight attendants are its end use customers and, therefore, must maintain a user's level of technical knowledge and related safety issues.

Another key link of the relationship is forged by the airworthiness concept. While the captain is responsible for ensuring the final airworthiness and safety of the aircraft, it is the maintenance department that maintains or returns an aircraft to an airworthy condition. A fundamental component of this link is the aircraft logbook, which serves to document the status, degradation, and restoration of the

aircraft between variable levels of serviceability.

The third component of the flight–maintenance–safety relationship is the regulatory-procedural link. Both procedural and technical regulatory issues must be closely coordinated. While regulatory requirements emanate from the FAA, they are often precipitated by NTSB investigative findings, thereby necessitating direct communication between agencies for effective implementation of evolving safety requirements. Because of the highly complex nature of modern aircraft, a means to quickly analyze and disseminate critical FAA and NTSB safety information is required. In addition, conduct of both major and minor technically oriented investigations will require in-depth and thorough coordination between these agencies. This is also true with foreign regulatory agencies; however, the specific processes vary widely between nations.

HOW TO IMPLEMENT SMS: A PHASED APPROACH

As noted earlier, 10 years ago, major U.S. Airlines were invited by the FAA to participate in the SMS Pilot Project to work closely with the FAA to establish a program of voluntary SMS implementation. Today we are in the midst of mandatory SMS implementation for FAR Part 21 airlines as previously described. The FAA provides further information on the current state of SMS Implementation as follows on its Web site: (www.faa.gov):

> *14 CFR Part 5 specifies a basic set of processes integral to an effective SMS but does not specify particular methods for implementing these processes. In other words, the regulation defines "what" must be accomplished, not "how" it must be accomplished. The current FAA Advisory Circular entitled: "Safety Management Systems for Aviation Service Providers" Dated: 1/8/15 (FAA AC No: 120-92B) provides additional guidance on how the SMS may be developed to achieve the safety performance objectives outlined by your organization. As is demonstrated by this AC, there is no one-size-fits-all method for complying with the requirements of Part 5. This design is intentional, in that the Federal Aviation Administration (FAA) expects each air carrier to develop an SMS that works for its unique operation.*

The classic implementation roadmap is set forth in a four-phased process similar to that outlined by the FAA and in the ICAO Safety Management Manual. The phases of implementation are arranged into four levels of "maturity" similar to that developed in the proven capability maturity model for software engineering at Carnegie-Mellon University in Pittsburgh, PA. Figure 12-11, from the FAA Web site, is an FAA depiction of this maturity model, which is further described.

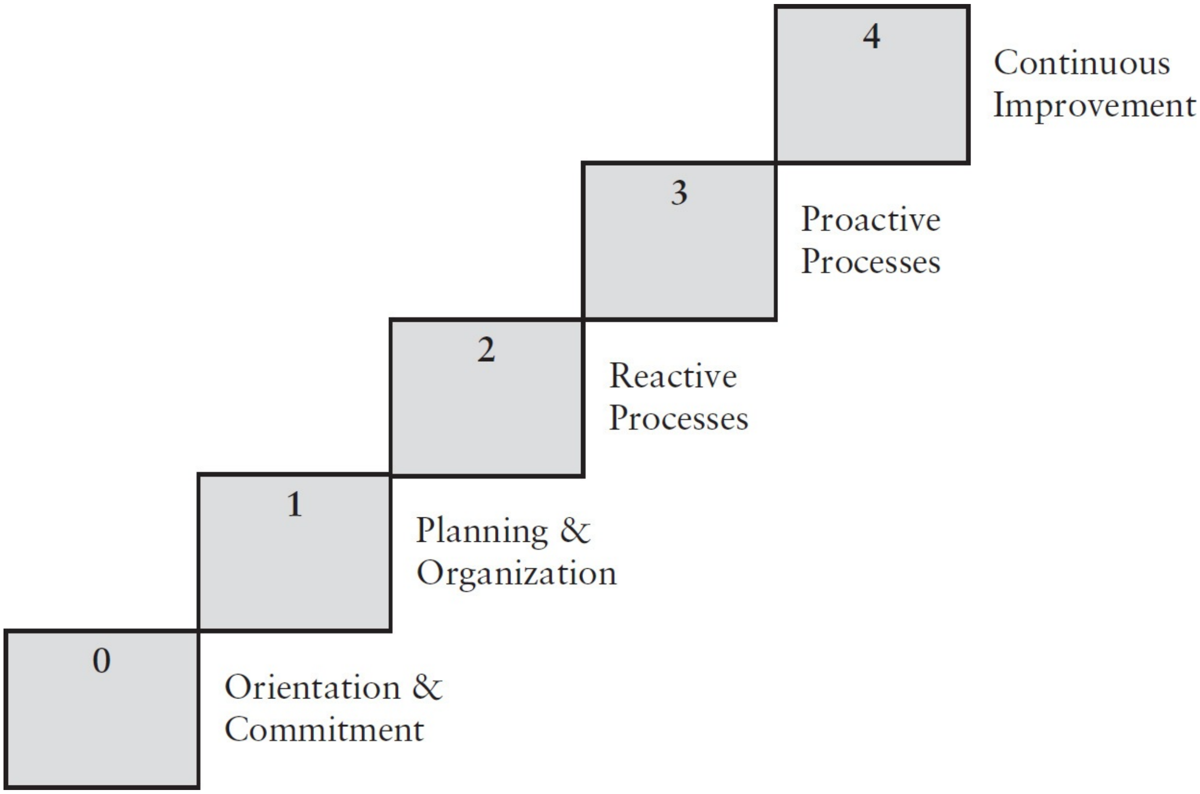

FIGURE 12-11 FAA SMS maturity model. (*Source: FAA*)

Each level of the SMS maturity model is explained as follows by the FAA:

1. *Level Zero*: Orientation and commitment is not so much a level as a status. It indicates that the Aviation Product/Service Provider has not started formal SMS development or implementation and includes the time period between an Aviation Product/Service Provider's first requests for information from the FAA on SMS implementation and when they commit to implementing an SMS.
2. *Level One*: planning and organization. Level One begins when an Aviation Product/Service Provider's Top Management commits to providing the resources necessary for full implementation of SMS throughout the organization. Two principal activities make up Level One:
   a. *Gap Analysis*: The first step in developing an SMS is for the organization to analyze its existing programs, systems, and activities with respect to the SMS functional expectations found in the SMS Framework. This analysis is a process and is called a "gap analysis," the "gaps" being those elements in the SMS Framework that are not already being performed by the Aviation Service Provider.

b. *Implementation Plan*: Once the gap analysis has been performed, an Implementation Plan is prepared. The Implementation Plan is simply a "road map" describing how the Aviation Service Provider intends to close the existing gaps by meeting the objectives and expectations in the SMS Framework.

3. *Level Two*: reactive process, basic risk management. At this level, the Aviation Service Provider develops and implements a basic safety risk management process. Information acquisition, processing, and analysis functions are implemented and a tracking system for risk control and corrective actions are established. At this phase, the Aviation Service Provider develops an awareness of hazards and responds with appropriate systematic application of preventative or corrective actions.

4. *Level Three*: proactive processes, looking ahead. At this level, the activities involved in the safety risk management process involve careful analysis of systems and tasks involved, identification of potential hazards in these functions, and development of risk controls. The risk management process developed at Level Two is used to analyze, document, and track these activities. At this level it can be said that the organization has a full-up, functioning SMS.

5. *Level Four*: continuous improvement, continued assurance. The final level of SMS maturity is the continuous improvement level. Processes have been in place and their performance and effectiveness have been verified. The complete safety assurance processes, including continuous monitoring, and the remaining features of the other safety risk management and safety assurance processes are functioning. A major objective of a successful SMS is to attain and maintain this continuous improvement status for the life of the organization. (*Source: www.faa.gov*)

FUTURE CHALLENGES

Today, the transformation of commercial aviation safety into the SMS framework is in full swing on a global basis. Using quality principles as a successful guide, SMS will continue to employ new methods with empowerment of employees and positive safety culture techniques to obtain safety levels never before achieved in commercial aviation.

This is not to say that there are no challenges ahead as SMS is integrated into daily operations. Stolzer and Goglia (2015) talk about some of these difficulties in their book, *Safety Management Systems in Aviation*, 2nd ed. A strong safety

record is not necessarily an accurate predictor of future safety performance. Currently, the literature available about SMS leans more toward developing and implementing programs, and there is somewhat of a gap of information regarding how to measure its effectiveness (see, Chapter 12, Stolzer and Goglia (2015) entitled “SMS Effectiveness” for a detailed discussion). For example, early metrics for measuring effectiveness were more reactive and measured accidents and incidents after they occurred. That method did not lend way to preventing future problems from occurring. Strong evaluation programs, then, should be developed to focus on both strengths and weaknesses of the SMS program in an attempt to improve the system. Organizations should move away from trying to eliminate the things that go wrong and work toward making sure as many things as possible go right. Moving forward in the development of SMS programs, we could expect to see a shift toward investigating right methods and practices as opposed to focusing on the wrong way to do things.

Currently, SMS effectiveness centers on the collection and aggregation of information from sources such as ASAP, FOQA, FAA surveillance, internal evaluation programs, and accident investigations. However, there is currently research assessing two new quantitative methods, both adopted from the business world, which could be used for future evaluation of SMS programs (Stolzer & Goglia, 2015, pp. 348–349).

- The first quantitative method is data envelopment analysis (DEA), a powerful technique to evaluate and benchmark organizations. DEA relies on linear programming, which is frequently used in operations research to evaluate the effectiveness of certain operational segments of an organization. It does this by using a math algorithm to consider all the inputs and resources used by each segment of an organization and comparing the relationships of the variables involved. Stolzer and Goglia (2015) explain that DEA is particularly useful when comparing “best practices.” The benefits of DEA would be that multiple inputs and outputs could be compared, and peer measurement could be ascertained.
- The second quantitative method of SMS effectiveness is Input–Output (IO) which analyzes the interdependencies between the various branches of an economy. Stolzer and Goglia (2015) state in their book that IO demonstrates how parts of a system are affected by any change in the system. Thus, the IO process would be very useful in the safety assurance phase of change management.

Researchers at Embry-Riddle Aeronautical University are currently exploring

these two methods for use on future SMS effectiveness studies. With the employment of these new DEA and IO tools, SMS effectiveness will be more scientific and less equivocal in the future.

As the March 2018 deadline for implementing Part 121 SMS approaches, airlines must be open to changes in culture and shifts in management philosophies. First, to be successful, senior leadership must have a strong, visible commitment to the four SMS components, or the four “Pillars” upon which SMS is based. Executives must also adopt a more democratic style of management while maintaining that not all ideas will be accepted and implemented despite being appreciated and considered. Companies should ease employees into this system using the phased implementation process, thus allowing the organizational culture to adapt and evolve to these new concepts. Adopting this enlightened mindset as soon as possible will facilitate successful implementation and smooth SMS execution in the years ahead.

ASRS EXAMPLES

Following are some examples from NASA’s Aviation Safety Reporting System (ASRS), in the original text submitted, including grammatical errors. These reports demonstrate the look and feel of operations that do not comply with SMS principles. Notice that, although each scenario is complex, several blatant warning signs exist showing that the situation is not following best SMS practices.

MAINTENANCE PROCEDURES AND FUEL SYSTEM MALFUNCTION

Title: Vastly different perspectives on safety between maintenance and flight crew.

In this report, a Boeing 737-800 First Officer discovers on the third leg of his flight that the fuel system is malfunctioning, causing fuel spills and uncontrolled fuel transfer between wings. A Maintenance Supervisor suggests that this situation is not mechanically possible, and the crew should take it flying and see what happens. The crew declines.

I served as the Relief Pilot for this flight. The trip started off with the aircraft was over fueled by 1,000 LBS by refueling personnel. A new Weight and Balance was obtained with the revised fuel weight and the flight departed uneventfully. The aircraft landed and refueled with no indications of a fuel system problem. Next leg was uneventful as well. While refueling ground personnel notified the pilots the aircraft was leaking something out of the left wing. I went to investigate while the Captain and First Officer remained in the cockpit. I observed fuel overflowing out the left wing at an extreme rate. I notified the Captain and at that same time refueling was terminated and the overflow condition ceased. I estimate 1,000–2,000 LBS were spilled. Clean up crews and Fire Department personnel began the clean

up as we de-boarded the aircraft. The on board Mechanic began to troubleshoot the system. While troubleshooting, I along with the crew viewed fuel transferring from one wing to the other with the fuel valve switches closed. This was concerning due to the fact that if this occurred airborne the aircraft would become uncontrollable after 5–10 minutes due to the imbalance. The Captain and the mechanic went to Operations to call Maintenance after troubleshooting. I was present during the conversation with the Captain when he was discussing the issue with a Mechanic on the phone. The Captain explained that with this uncontrollable fuel transfer to one wing the aircraft would not be safe to fly until it was positively fixed. The discussion heated as the Captain said, "He was not going to take the Mechanic's advice to go fly and see what happens airborne." The conversation ended with the Captain explaining that the aircraft was not going to fly when he, the First Officer, the Relief Pilot and the on board Mechanic refuse to fly for safety.

Following the phone call I talked with the Captain further about the phone call. He stated, the mechanic said this situation was not mechanically possible and the crew should take it flying and see what happens. He also told me the mechanic said, "Pilots what if situations too much." The Captain and First Officer then taxied the aircraft to a new parking spot. When they returned they stated the fuel once again transferred uncontrollably to one wing. Not one member of the crew wanted to lose a day and desired to have their full planned layover, but safety dictated that it was not safe to fly that aircraft until the mechanical situation was positively identified and resolved.

The whole crew was placed in a hotel for the night until a rescue flight arrived the next day. At that point we took the new aircraft and the rescue crew took our aircraft after the plane's defuel valve was manually closed. Later I talked with two different on board mechanics. They said that the manual defueling handle broke open and that there was also a refueling valve that was broken. He also stated this aircraft had an issue prior to our flight. I have several safety concerns listed below as it relates to this situation.

1. *There was no write up in the aircraft logbook about any such fuel system issue prior to our flight so there was no way a crew would know of such issues before they take the aircraft.*
2. *The over fueling of the aircraft initially may have been caused by the system actually being broken prior to the start of the flight and there are no procedures with refueling personnel to catch this problem.*
3. *This issue could be occurring with our other aircraft in the fleet and there should be a fleet wide inspection of these system components.*
4. *My last and greatest concern is with the Maintenance Supervisor who was on the call with the Captain and the potential lack of safety culture at the management level within the Maintenance Department. When the Captain states he is not comfortable to fly along with the entire crew to include the onboard mechanic then those statements should be listened to. Pushing a crew to fly the aircraft and see what happens is not an environment that promotes safety first and could end with disastrous results. That type of culture will cause the airline to lose an aircraft and lives.*

Question for the reader: Please explain the aspects of the scenario that did not follow SMS best practices.

BOEING 757 STALL WARNING SYSTEM FAULT

Title: Miscommunication from confusing maintenance directions.

In this report, a Boeing 757-200 flight crew receives a message on their Engine Indicating and Crew Alerting System (EICAS), which is a large flight deck display, as they taxied for takeoff. They returned to the gate for maintenance action which ultimately required several days to complete after determining the fault was a severed wire to the First Officer's stick shaker. When later advised by management that they could have legally flown the flight from Hawaii to the mainland and simply written up the message in the maintenance logbook, the captain, who was newly qualified in this type of aircraft, was incredulous and requested an explanation.

I am new on the fleet with about 150 hours total time. My First Officer has many hours. During taxi out the First Officer performed flight control checks and observed a white STATUS message on the lower EICAS screen "WARN ELEX." Neither of us had ever seen this message. I stopped the aircraft and parked the brakes. We found a pertinent MEL which seemed to apply. It showed that it was NOT flight crew placardable. I contacted Dispatch and Maintenance Control. Together we determined that we needed to return to the gate for maintenance action. Every time we moved the yoke fore and aft we got the WARN ELEX status message, and after we centered the yoke in the neutral position, the status message would go out after about 10 seconds.

After almost three days of maintenance troubleshooting, parts shipments, and an imported maintenance crew from the mainland, a partially severed wire leading to the First Officer's stick shaker about a foot below the First Officer's yoke was found. The wire had only a few strands of wire connecting the two sides. Apparently, there was enough damage to trigger the WARN ELEX message, but enough wire left to activate the stick shaker when it was tested. Eventually, the mechanics manipulated the yoke enough that the damaged wire completely severed the remaining strands, and then the First Officer's stick shaker would no longer work. The damaged wire was then properly repaired, and the problem was corrected, prior to an actual failure! That is how the system should work, when problems are identified and repaired before an actual failure takes place in the air!

In the aftermath of this event, I have been told by very senior company management pilots that, in this event, I "could" have legally continued the operation to takeoff and fly across the ocean with the white WARN ELEX status message showing. They have told me that this is in compliance with Boeing's procedures.

I feel alarmed that this is true! The apparently applicable MEL shows this is not flight crew placardable. Perhaps there are "some" status messages where it would not be a safety issue to operate with a status message showing prior to takeoff, but who in their right mind would even consider taking off to fly across the ocean when the aircraft is telling you that there is an unknown problem with the stall warning system? Why would senior management pilots tell me that? This is such a "Black and White" safety issue to me that I am very concerned that some other Captain might have ignored this STATUS message, in compliance with Boeing and company procedures, and taken the aircraft to the mainland from the islands. In my event, there was an actual problem, which had we taken off, could have resulted in a real inflight failure of some part of our Stall Warning system.

I think that there should be some disclaimer to the policy which allows crew to "disregard" status

messages prior to takeoff. Obviously, some status messages are more important than others. I am totally comfortable with my decisions in this event, but I question the "safety" of a policy which clearly conflicts with the MEL, which states that I cannot flight crew placard this issue, but if it happens after "brake release," and before takeoff, that I can just "ignore" it, as if it never happened. This is not a smart procedure, for sure.

Question for the reader: Please explain what aspects of this scenario show strengths in the airline's SMS and what parts show SMS weaknesses.

CONCLUSION

Despite aviation being one of the safest modes of transportation in the world, accidents still happen. To counter the accidents that do occur, over the past several decades, our industry has adopted new mindsets and practices to make the aviation environment a safer place. One important way we have done this is by requiring the adoption of SMS both on the international and domestic level. Although safety management as a practice has existed since the birth of aviation, SMS is a formal and standardized framework for managing a safety program based upon accepted business and scientific processes.

Figure 12-12 shows the pilots of an Airbus A330 skimming over cloud tops. Such an image may be what first comes to mind when contemplating SMS in commercial aviation. The reality is that SMS starts deep in the back offices of air service providers where executives and safety professionals, often teamed with union safety representatives, work to adopt the tenets of SMS. The same occurs in aviation venues ranging from airports, maintenance offices, air traffic control towers, and all other aviation organizations. Each of those links in the commercial aviation safety value chain must have a robust and continuously improving SMS as their lifeblood. Otherwise, as the saying goes, a chain is only as strong as its weakest link.

FIGURE 12-12 Pilots are but one of the many links in the commercial aviation safety value chain. (*Source: Wikimedia Commons*)

The four components of SMS, as developed by ICAO and FAA, and adopted by many throughout the world, provide a systematic approach for achieving new levels of safety that were originally unattainable. Simply stated, *Safety Policy* means *document it in writing*, referring to the need to have key aspects of a given SMS readily available to employees as a written reference. *Safety Risk Management* is the means to *hunt the hazards, then assess and mitigate the risks*, referring to the fundamental need of having employees aggressively seek safety problems and having a means of effecting change to produce better conditions. *Safety Assurance* is the way to *measure and improve it*, referring to the need to use scientific principles to determine the value of the actual management processes being used. Lastly, but affecting all other components, *Safety Promotion* is the *learning and sharing* of everything in all the components.

Although the road to SMS has been long and sometimes difficult, for students of SMS the future is very bright indeed. The next few years will bring increased international collaboration and employment opportunities. Aviation safety professionals will find that SMS is a journey of continuous improvement, not a final destination.

KEY TERMS

Accountable Executive
Analysis of Data
As Low As Reasonably Practicable (ALARP)
Continuous Monitoring
Design and Engineering
Emergency Response Plan (ERP)
Employee Reporting System
External Audits
Gap Analysis
Hazard
Human Era
ICAO Annex 19
Implementation Plan
Internal Audits
Internal Evaluation Audits
Investigations
Organizational Era
Personal Protective Equipment
Probability
Procedures and Training
Risk
Safety Action Group (SAG)
Safety Devices
Safety Management Systems (SMS)
Safety Performance Indicator (SPI)
Safety Review Board (SRB)
Safety Training Program
Severity
System Assessment
Technical Era
The Four Components of SMS
- Safety Assurance
- Safety Policy
- Safety Promotion
- Safety Risk Management

Safety Risk Management
Warning Devices

REVIEW QUESTIONS

1. Discuss the evolution of SMS principles.
2. List and discuss the salient features of the Four Components of SMS.
3. Explain how safety assurance relates to safety risk management.
4. What is the concept of ALARP and why is it significant?
5. Compare and contrast the differences between hazards and risks.
6. Provide an example of why change management is such a critical aspect of SMS.
7. Discuss which SMS component you think is the most important. Back up your answer with a specific example.
8. Select a sample and very specific hazard for a commercial aviation operator. Assess the risk presented by the hazard and recommend several controls.
9. Why is communication important to SMS?
10. Describe the steps of the SMS maturity model used for SMS implementation.
11. Discuss the future of Safety Management Systems in aviation to today's aviation safety professional.

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CHAPTER THIRTEEN

PROTECTION FROM INTENTIONAL HARM (SECURITY)

LEARNING OBJECTIVES

After completing this chapter, you should be able to

- Distinguish between security and safety.
- List the categories of attacks on civil aviation.
- Discuss the regulatory and legislative aspects of aviation security.
- Explain the role of the Transportation Security Administration (TSA).
- Discuss the role of intelligence gathering and analysis regarding the security threat.
- Explain the mission of the National Counterterrorism Center (NCTC).
- Discuss the importance of the Intelligence Reform and Terrorism Prevention Act of 2004 (IRTPA).
- Discuss the theory and concepts behind aviation security technologies and strategies.
- Elaborate on the threat of cyberattacks in the aviation community.
- Detail measures that the aviation industry has taken to increase cybersecurity.

INTRODUCTION

"Security" and "safety" are often used by the public as interchangeable terms and sometimes are even considered synonymous topics. In modern society, the discussion of one invariably invokes references to the other. However, it is important to realize that there is a fundamental difference between the two terms. While the end objective of both safety and security is to prevent injuries, loss of life, and property damage by minimizing risk, *safety* practices are designed to prevent "unintentional" acts and harm whereas *security* practices are designed to avert "intentional" acts and harm. The intentional acts addressed in this chapter are focused on attacks against commercial aviation. While attacks on civil

aviation can be carried out against airliners, airports, and airline offices, airliners have been the most common target for attacks.

The spectrum of attacks on civil aviation includes the following:

- Bombings, shooting, and other attacks at airports
- Bombings, shooting, hijackings, and other attacks (e.g., commandeering) on aircraft on the ground or in flight
- General-aviation and charter-aviation aircraft attacks
- Off-airport facility attacks, such as to navigation aids or communication relays
- Shootings (from the ground) at aircraft during takeoff and landing
- Virtual or cybernetic attacks from remote locations

An example of how a large-scale attack by a highly trained group of terrorists can completely bring commercial aviation to its knees occurred on September 11, 2001, when al-Qaeda carried out four simultaneous and closely coordinated suicide hijacking attacks. Later that year, al-Qaeda announced that its number one goal was to incapacitate the U.S. economy. Although this was not the first act of terrorism directed toward airlines, it proved particularly detrimental to the global economy. Some of the financial repercussions associated with attacks on the airline industry include the need to reallocate resources to enhance security measures and the crippling of air transportation systems, all at an enormous cost to the airline industry.

As we move into the next era of aviation, we expect to see more of a relatively new type of violence to emerge: the cyberattack. We therefore need to start thinking about not only protecting the physical components of the system, such as planes, people, and facilities, but also consider the security of technology, such as software and digital information. Cyberattack threats will pose a new set of challenges for keeping our airspace secure. In this chapter, we review the history of attacks against commercial aviation together with the regulations and security measures that have evolved to minimize the occurrence and severity of these attacks. Figure 13-1 shows TSA inspectors patrolling airside ramp gates at an airport.

FIGURE 13-1 TSA security inspectors on the job. (*Source: TSA*)

REVIEW OF ATTACKS ON CIVIL AVIATION

The first significant attack on commercial aviation dates back to 1930 when Peruvian revolutionaries seized a Fokker F-7 aircraft in South America. The incident received little attention and never resulted in any international effort to combat potential threats to international aviation. At the time of ICAO's formation in Chicago in 1944, few foresaw aviation security threats as significant, and hence, it was not addressed. Until the mid-1960s, airlines and airports gave security matters little attention. Low-technology security measures, such as airport fences, were intended as a safety measure to separate aircraft from wildlife rather than terrorists.

In the United States, only 12 commercial aircraft hijackings were attempted from 1930 to 1967, of which only seven were semi-successful (Dorey, 1987), and there were only 32 worldwide hijackings from 1961 through 1967. However, attacks against civil aviation rose rapidly in the late 1960s and 1970s

However, attacks against civil aviation rose rapidly in the late 1960s and 1970s. In 1968 there was a surge of hijackings in the United States in which several flights traveling to the Caribbean were repeatedly detoured to Havana, Cuba. Of the 22 hijackings in 1968, 19 of these flights were redirected to Cuba. There were 290 hijacking attempts (successful and unsuccessful) worldwide during the 4 years following 1968. The worst year occurred in 1969 when 33 regularly scheduled U.S. airliners were hijacked (seven of these attempts failed). By 1969, the number of U.S. passengers and crewmembers who were being detoured to Cuba totaled 1,359 (Moore, 1991).

From 1947 to 1996 there were 1,098 total incidents of attacks on airliners, compared with 129 attacks on airports and 249 attacks on airline offices. Unlike attacks on airliners, attacks on airports (bombing and armed assaults) peaked in the 1977–1986 decade. With regard to the modes of attack, hijackings were by far the most common form of attack on commercial aviation. Hijackings constituted 87% (959 of 1,098) of all incidents on airliners during this 50-year period. The other significant forms of attack on airliners were bombings (on the ground or in midflight) and armed assault (shooting at aircraft on the ground or in flight, throwing hand grenades, etc.).

Throughout those key decades of the 1960s through 1980s, the overall number of attacks against commercial aviation were on a decline, but the severity of these attacks grew increasingly worse. In fact, the 1980s can be considered a disastrous decade for commercial aviation security, since 25 planes were sabotaged by explosives, causing 1,237 casualties. Some of the more infamous incidents included the following:

- Air India Flight 182 in 1985 was a Boeing 747 that exploded due to a bomb, causing the death of 329 people off the coast of Ireland.
- The Korean Air Flight 858 disaster in 1987 in which 115 lost their lives due to a terrorist bomb exploding on a Boeing 707 in Asia.
- Pan Am Flight 103 was an infamous bombing of a Boeing 747 in 1988 caused by a Libyan terrorist bomb in the baggage compartment over Lockerbie, Scotland (270 fatalities).
- The bombing of UTA Flight 772 in 1989 over the Niger desert in Africa in which 171 were killed.
- The bombing of Avianca Flight 203 in 1989 near Bogotá in which 107 people died.

In addition to these attacks, there were 17 other documented, failed attempts

between 1982 and 1987, as noted in the President's 1989 Commission Report on Aviation Security and Terrorism. By comparison, there were 650 deaths in the 1970s and 286 deaths in the 1960s. Things cooled off in the 1990s only to give way to the events of September 11, 2001, when 2,996 victims were killed in the four separate terrorist acts that will be discussed later in this chapter.

The increased severity of attacks on commercial aviation were the results of terrorists changing their tactics and philosophies and making use of new technologies. They gained access to more sophisticated and lethal technologies, such as automatic weapons and deadly plastic explosives. They attacked airports by using pistols and bazookas, and they developed numerous ingenious ways to turn innocuous-looking suitcases and radios into lethal bombs. The character of airline hijackings also changed from the lone hijacker of the early 1960s who was making a personal or political point to an organized terrorist tactic in the 1970s. In the era leading up to September 11, 2001, hijacking for the most part did not usually cost the lives of hostages. The operating security philosophy was to negotiate with the hijackers until a peaceful settlement was reached, thereby minimizing casualties.

One particularly memorable event in commercial aviation security history took place in June and July 1976 and is best known as Operation Entebbe. On July 4, 1976, an Air France Airbus 300 aircraft with 248 passengers aboard was successfully rescued from hijackers associated with the Popular Front for the Liberation of Palestine. The terrorists' intent was to force the release of Palestinians and militants imprisoned by Israel in exchange for the hostages. The flight had started in Tel Aviv with a destination of Paris but was diverted to numerous locations before stopping at Entebbe, which was the main airport in the African country of Uganda. Although 148 non-Israeli hostages were released, 94 mostly Israeli passengers and the Air France crewmembers remained hostages and were at grave risk of being killed. In response, the Israel Defense Forces transported 100 commandos over 2,500 miles to effect a daring night-time rescue mission in Entebbe. After a week of planning, the 90-minute raid rescued 102 hostages, but unfortunately cost the life of the Israeli unit commander and three hostages. All the hijackers were killed (Dunstan, 2011). Figure 13-2 shows the moment when the released hostages made it to freedom.

FIGURE 13-2 Air France hostages returning home after being rescued by Israeli commandos in Entebbe, Uganda. (*Source: Wikimedia Commons*)

During the following decade, hijackings have been largely unsuccessful, and aircraft defenses have significantly improved. Flight attendants and pilots now receive extensive anti-hijacking training. Passengers have also helped prevent terrorists from igniting explosives, such as during the shoe bombing attempt of December 22, 2001, and the underwear bombing attempt of December 25, 2009. Hijackers have been arrested and brought to justice in nearly every incident since September 11, 2001.

REGULATORY MOVEMENT

The terrorist attacks of September 11, 2001 changed the Aviation Security (AVSEC) landscape across the globe on a permanent basis. There have been significant regulatory developments in the international arena and in U.S. policy along the way. The international developments will be discussed briefly, followed by a historical discussion of the evolution of aviation security in the

United States.

INTERNATIONAL RESPONSE TO TERRORISM

As stated above, no one considered aviation security as a major issue at the time of the formation of ICAO at the Chicago Convention in 1944. The focus at that time was the planning and development of air transport to ensure safety of flight in international air navigation. Gradually, through a series of ICAO meetings and conferences, the international community began to focus on crimes committed onboard aircraft. Some major milestones of international aviation security include the following:

- *Tokyo Convention* recognized the issues underlying offenses and certain other acts committed on board aircraft (1963) and authorized the airline captain to take appropriate action to restrain persons interfering with safety of flight.
- *Hague Convention*, for the suppression of unlawful seizure of aircraft (1970), adopted 14 articles relating to hijacking and provided guidelines to governments dealing with this problem.
- *International Civil Aviation Organization (ICAO) Annex 17*—SARP (Standard and Recommended Practice) entitled "Security-Safeguarding International Civil Aviation against Acts of Unlawful Interference" (1974). This SARP sets forth the basis for the ICAO Civil Aviation Security program and outlines the minimum standards for aviation security worldwide. It has been a living document, evolving with security problems around the world. *ICAO Security Manual*—(Doc 8973—restricted) is the primary document providing member States with guidance material to assist with the implementation of international security measures. The ninth edition is the most recent version and includes national organization and administration; recruitment, selection, and training; airport security, organization, program, and design requirements; preventive security measures; and crisis management and response to acts of unlawful interference.

In recent years, ICAO has been deeply involved in strengthening worldwide aviation security. Some current developments are provided below; for future updates please visit www.icao.int/security.

- During a United Nations Security Council meeting in September 2016, the group unanimously adopted UN Resolution 2309 (2016), which calls for closer collaboration to ensure the safety of all global air services and prevent

terrorist attacks. To counter the ongoing danger posed by terrorism to civil aviation, the Security Council called on all States to work with each other and the International Civil Aviation Organization (ICAO) to continuously adapt measures to meet that "ever-evolving global threat" (www.un.org).

- Along with enhanced screening, security checks, and facility security, the UN Security Council called for strengthened cooperation and information-sharing among States and a requirement that airlines provide advance passenger information to national authorities in order to track the movement of individuals identified by the counter terrorism committees. Regional and international cooperation on border control, law-enforcement, and criminal justice was also emphasized.
- One of the major features of worldwide security is the ICAO Universal Security Audit Programme Continuous Monitoring Approach (USAP-CMA), which has an ongoing objective to promote global aviation security through continuous auditing and monitoring of member States' aviation security performance.
- The International Civil Aviation Organization (ICAO), International Air Transport Association (IATA), and Airports Council International (ACI) jointly convened the 25th AVSEC World Conference in Kuala Lumpur, Malaysia from October 25 to 27, 2016. More than 450 security representatives from around the world exchanged ideas and operational experiences, learned practical new skills, and put together the framework to create the future of aviation security.
- IATA *Security Management System (SeMS)*. This system sets out an organization's security policies as an integral part of its business processes. SeMS is based on the same concepts used for Safety Management System (SMS). Developed in conjunction with an efficient threat assessment mechanism and risk management program, SeMS helps organizations develop proactive, efficient, and cost-effective security measures (www.iata.org).

EVOLUTION OF AVIATION SECURITY IN THE UNITED STATES

Similar to ICAO, the FAA response to aviation security has slowly evolved. This section will briefly discuss the history of aviation security in the United States and the changes brought about by the events of September 11, 2001.

THE HIJACKING ERA (1968–1987). In response to the major increase in hijackings during this era, FAA began to beef up the Federal Aviation

Regulations. Initially, airport security matters were governed under FAR Part 139. Part 139 was mainly concerned with deterring mistaken entry of humans and animals into air operations areas. However, to stem the increase of hijackings during the 1970s, there was a need to specifically deter access to air operations areas by individuals and ground vehicles that were unauthorized to do so. The anti-hijacking preventive measures ultimately approved were expensive, but so were the acts that were being prevented. Figure 13-3 shows a Federal Bureau of Investigation (FBI) Special Weapons and Tactics (SWAT) Team practicing an anti-hijacking response.

FIGURE 13-3 FBI anti-hijacking drill at a military air base. (*Source: U.S. Air Force*)

AIR CARRIER SECURITY. On January 31, 1972, Federal Aviation Regulation (FAR) 121.538 was issued to cover the air carrier community. Within this rule, air carriers were required to adopt and implement a screening system that would detect weapons and explosives in carry-on baggage or worn by passengers. The carrier’s security program was required to do the following:

- Prevent or deter unauthorized access to its aircraft
- Ensure that a responsible agent or representative of the airline would check in baggage
- Prevent cargo and checked baggage from being loaded aboard its aircraft unless they were handled in accordance with the certificate holder's security procedures

The *Anti-hijacking or Air Transportation Security Act of 1974* provided the statutory basis for the rules requiring carriers to institute 100% screening of passenger and carry-on items and for airport operators to station at least one law enforcement officer at each passenger checkpoint during boarding and pre-boarding. Additionally, as part of its obligation under this Act, the FAA began a research and development program that emphasized the development of devices to protect air travelers against acts of criminal violence and aircraft piracy.

Airlines not only had complete discretion on how they implemented these new requirements but also had the right to express their concerns and suggest changes based on trial and error. This resulted in the inconsistent application of regulations across the airline industry, and in early 1975, the Air Transportation Association sought to work out a single standard security program. Their effort produced the FAA's Air Carrier Standard Security Program, which attempted to bring some structure to the diverse interpretations of the new rules. Today, the Transportation Security Administration (TSA) has continued this program now known as the Aircraft Operations Standard Security Program (AOSSP).

The increase in the rate of hijackings during the late 1960s and early 1970s caused the public to exert pressure on the U.S. government to implement security procedures at airports and to mandate security requirements for U.S. air carriers. This resulted in the establishment of the Anti-Hijacking Program of the Federal Aviation Administration. One element of this program was the federal Air Marshal Program, which began as the Sky Marshal Program in 1968 and continued through the 1970s and part of the 1980s as a program that was initially instituted to stop hijackings to and from Cuba, given the dramatic political events that had taken place on the island in 1959 and subsequent years.

The Air Marshal Program gained importance, however, after the hijacking of TWA Flight 847 in June 1985 when two Lebanese hijacked a Boeing 727 departing from Athens and diverted it to Beirut, where they were joined by additional hijackers. During an excruciatingly long 2-week confrontation, the hijackers demanded the release of prisoners held by Israel and murdered Robert Stethem, a U.S. Navy diver who was a passenger aboard the plane.

In response to this hostage nightmare and the rapid surge in the Middle East terrorism, President Ronald Reagan directed the Secretary of Transportation, in cooperation with the Secretary of State and the Attorney General, to immediately explore an expansion of the FAA's armed Air Marshal Program aboard international flights for U.S. air carriers. On August 8, 1985, Congress enacted Public Law 99-83, *the International Security and Development Cooperation Act,* which established the explicit statutory basis for the FAA Federal Air Marshal Program and allowed for assessment of security at foreign airports and approval of foreign air carrier security programs.

This statute authorized Federal Air Marshals to carry firearms on board and to make arrests without warrant for any offense against the United States committed in their presence, if they had reasonable basis to believe that the person to be arrested had committed or was committing a felony. Three weeks after the TWA Flight 847 hijacking, the FAA imposed new regulations requiring that all scheduled carriers and public charter operators carry Federal Air Marshals on a priority basis, without charge, and that they provide seating selected by the marshals, even though it might mean bumping full-fare passengers. Today TSA has assumed responsibility for the Federal Air Marshal Service whose mission is to detect, deter, and defeat hostile acts targeting U.S. air carriers, airports, passengers, and crews. Figure 13-4 shows air marshals in rigorous hand-to-hand combat training.

FIGURE 13-4 Intensive federal air marshal training. (*Source: TSA*)

THE BOMBING ERA (1988–2000). On December 21, 1988, Pan Am Flight 103 exploded over the village of Lockerbie, Scotland, killing the 259 people aboard and 11 people on the ground, as well as damaging several residential buildings. As previously noted, the crash was due to the explosion of a terrorist bomb placed in the luggage compartment of the aircraft. It was asserted that the luggage was coming from passengers boarding in Frankfurt and from some possible suitcases transferred from Air Malta Flight 180 to Pan Am Flight 103 at the Frankfurt Airport. Figure 13-5 shows some of the many pieces of debris that were scattered across parts of Scotland due to the high-altitude explosion that tore the aircraft apart.

FIGURE 13-5 Part of the flight deck from Pan Am Flight 103 lying in a Scottish field. (*Source: Wikimedia Commons*)

The major lesson learned from the Pan Am tragedy is the importance of reconciling baggage to passengers, which is sometimes called *bag matching*. U.S. carriers were required to conduct a positive baggage–passenger reconciliation in 1988 at designated international locations. According to investigation findings, the Pan Am tragedy occurred because the airline was x-raying all interline bags at certain international high-threat locations instead of conducting a reconciliation process and physically searching all unaccompanied bags. Because Pan Am did not identify and physically search all the unaccompanied interline bags, Flight 103 left Frankfurt with several extra bags, one of which contained a bomb.

This failure was duly noted in the 1990 report of the United States' Presidential Commission on Aviation Security and Terrorism, established in the aftermath of the disaster. The commission's mandate was to comprehensively study and evaluate the practices and policy options with respect to preventing terrorist acts involving aviation. The commission made a number of recommendations to prevent the recurrence of such a tragedy. The *Aviation Security Improvement Act of 1990* (U.S. Public Law 101-604), passed on November 16, 1990, implemented many of the recommendations of the

commission. This Act has been described in the 1992 FAA Annual Report to Congress as perhaps the most comprehensive, far-reaching legislative initiative designed to improve all aspects of aviation security. It mandated many regulatory actions affecting several agencies, required new reports, created new organizations and staffing requirements, and empowered the FAA to promote and strengthen aviation security through an expedited, more focused research and development (R&D) program.

WHITE HOUSE COMMISSION ON AVIATION SAFETY AND SECURITY, 1996. The late 1990s witnessed significant changes in the direction and emphasis of aviation security in the United States. The triggering event for this new emphasis and importance was the catastrophic loss of TWA Flight 800 off Long Island, New York, in July 1996. The early model Boeing 747 was carrying 230 passengers and crew when it exploded minutes after departing John F. Kennedy International Airport, bound for Paris. The tremendous force of the explosion had torn the aircraft apart, and the disturbing recovery images, along with vivid eyewitness accounts, riveted the attention of a shocked U.S. public for many weeks fearing that a terrorist attack had occurred. Curiously, the FBI eventually ruled that TWA 800 was not the result of a terrorist act. Both the NTSB and FBI jointly investigated the event until it was ruled a matter of safety and not security, at which point the NTSB finished the investigation.

Nevertheless, the traveling public was frightened, and the media questioned the perceived safety and security of domestic airline operations. Within weeks, President Clinton announced the creation of the *White House Commission on Aviation Safety and Security (the Gore Commission)* which outlined sweeping changes, calling for regulatory reform and additional research directed toward new, safer technologies. Special attention was given to an action plan to deploy new, high-technology machines to detect the most sophisticated explosives. The report included 57 recommendations, 31 dealing with improvements in security for the traveling public. The commission recommended that the federal government consider aviation security a national security concern.

GLOBAL WAR ON TERRORISM (2001 TO PRESENT). On September 11, 2001, four passenger aircraft were hijacked and crashed by terrorists in a coordinated attack against the United States of America. The terrorist events of 2001 changed the face of aviation forever while fundamentally modifying the thinking and approach to security in the United States. The ramifications of the attacks extend beyond trends and measures of security in aviation and into all modes of transportation.

The first airplane used in the attacks was American Airlines 767 (Flight 11), which was flying from Boston to Los Angeles when it was hijacked and flown into one of the World Trade Center towers. All 11 crewmembers, 76 passengers, and 5 hijackers were killed. The second jet that was crashed into the second World Trade Center tower was United Airlines 767 (Flight 175). All 9 crewmembers, 51 passengers, and 5 hijackers were killed. The impacts against the towers, together with the heat generated from the explosion of the aircraft, caused both towers to collapse. The third aircraft was American Airlines 757 (Flight 77) on a flight from Dulles to Los Angeles. It was hijacked and flown into the Pentagon, collapsing part of the structure. All 6 crewmembers, 53 passengers, and 5 hijackers were killed. The fourth aircraft was United Airlines 757 (Flight 93) on a flight from Newark to San Francisco. It was hijacked and crashed into a field near Pittsburgh. All 7 crewmembers, 34 passengers, and 4 hijackers were killed. Figure 13-6 shows firefighters extinguishing the fire from the impact of the hijacked aircraft that crashed into the Pentagon at approximately 9:30 in the morning of September 11, 2001. Next, the U.S. response to these attacks will be discussed.

FIGURE 13-6 Firefighters extinguishing flames at the Pentagon caused by a 9-11 attack. (*Source: U.S. Marine Corps*)

THE 9-11 COMMISSION. The National Commission on Terrorist Attacks upon the United States (*the 9-11 Commission*) was an independent, bipartisan commission created by Congress and the President to prepare a full and complete account of the circumstances surrounding the terrorist attacks, and to provide recommendations designed to guard against future attacks. The full comprehensive report of the commission was issued on July 22, 2004, consisting of 585 pages. The executive summary of the report, which is available on the 9-11 Commission's Web site, outlines sweeping general and specific findings, plus numerous recommendations (www.9-11commission.gov).

General findings:

- *Imagination*. The most important failure was one of imagination. The Commission did not believe national leaders understood the gravity of the

terrorist threat.

- *Policy*. Terrorism was not the overriding national security concern for the U.S. government.
- *Capabilities*. The United States tried to solve the al-Qaeda problem with old, insufficient, Cold War capabilities.
- *Management*. The United States missed opportunities to thwart the 9-11 plot, and could not find a way to pool intelligence information.

Specific weakness and adverse findings were made by the 9-11 Commission in the following areas:

- Unsuccessful diplomacy.
- Lack of military options.
- Problems within the intelligence community.
- Problems in the FBI.
- Permeable borders and immigration controls.
- Permeable aviation security system.
- Al-Qaeda financing was not detected.
- The United States had an improvised homeland defense and communication was poor at senior government levels.
- Emergency response was determined and saved lives, but effective decision making in New York was hampered by poor communication and weak command and control.
- Congress and the Executive Branch responded slowly to the rise of the transnational terrorism threat.
- The Commission stated that at the time of the report (2004), the United States was more secure than on September 11, 2001, but even more measures could be taken; therefore, recommendations were issued as follows.

The 9-11 Commission recommended that the United States should take the following steps:

1. Attack terrorists and their organizations
2. Prevent the continued growth of Islamic terrorism
3. Protect against and prepare for future terrorist attacks

The 9-11 Commission specifically recommended the following

The 9-11 Commission specifically recommended the following:

1. Creation of a National Counterterrorism Center
2. Creation of a new National Intelligence Director
3. Effective sharing of information across U.S. government agency boundaries
4. Congressional action to improve oversight of homeland security
5. Clarification of roles, missions, and authority between Department of Defense (DoD) and Department of Homeland Security (DHS) officials among other agencies

TRANSPORTATION SECURITY ADMINISTRATION

On November 19, 2001, Congress enacted the *Aviation and Transportation Security Act (ATSA)*, Public Law 107-71, 115 Stat. 597, which established the *Transportation Security Administration (TSA)* as an operating administration within the Department of Transportation (DOT). A year later, on November 28, 2002, Congress enacted *the Homeland Security Act* Public Law 107-296, 117 Stat. 745, which created the *Department of Homeland Security (DHS)* and is headed by a cabinet-level secretary. The TSA subsequently moved from the DOT to the DHS in March 2003 as part of a massive federal government integration of all agencies whose mission it was to prepare for, respond to, and protect the United States from domestic emergencies, especially terrorism.

According to its Web site, the mission of the TSA is to protect the nation's transportation systems to ensure freedom of movement for people and commerce. Security screening is at the heart of the TSA, which now numbers approximately well over 50,000 employees. The TSA conducts 100% passenger screening and handled 708 million people in 2015. The multiple layers of the TSA aviation security system include the following:

- Airport document checkers.
- Behavior detection officers.
- Secure flight—the behind-the-scenes watch list which matches passenger names to government lists of suspected terrorists.
- Federal Air Marshals who fly aboard selected U.S. commercial aircraft.
- Federal Flight Deck Officers (FFDOs) who are pilots armed and trained by the Federal Air Marshal Service on the use of firearms and other tactics.
- Crewmember self-defense training program available at over 20 sites across

the country.

- Mobile dog explosive detection teams, such as the one shown in Figure 13-7.

FIGURE 13-7 A mobile dog explosive detection team at Washington Dulles International Airport. (*Source: TSA*)

- Air cargo programs and initiatives such as the Certified Cargo Screening program to allow the prescreening of cargo prior to arrival at the airport. This program is part of the Improving America's Security Act of 2007, Public Law 110-53, which implements the ambitious 9-11 Commission recommendation mandating 100% inspection of all air and sea cargo entering the United States.

TSA Regulations

The TSA issues Transportation Security Regulations (TSRs), which are codified in 49 CFR Chapter XII, Parts 1500 through 1699. TSA regulations are broken out into subchapters. Subchapter A contains administrative and procedural rules.

Subchapter B contains rules that apply to many modes of transportation. Rules for civil aviation security are contained in Subchapter C.

Subchapter A, 49 CFR 1500, outlines and defines the terms used in the TSRs.

- *Part 1520* addresses the protection of sensitive security information. This part outlines the type of information that may not be released under the Freedom of Information Act. Contained in this section is the duty to protect any information that is given to a person in performance of his or her duties and the responsibility to report to TSA, DHS, or DOT when he or she becomes aware that sensitive security information has been released to unauthorized individuals.
- *Part 1540* outlines the Civil Aviation Security General Rules. Part 1540 also contains prohibitions regarding making fraudulent or intentionally false statements or entries in compliance reports. Also prohibited by Part 1540 is the interference with screening personnel while they are performing their duties and the carriage of weapons, explosives, or incendiaries by individuals into specified areas at airports. Other requirements outlined in Part 1540 are as follows:
  - The security responsibilities of employees and persons who access the airport
  - The responsibilities of persons who wish to enter any area that requires screening
  - The responsibility of airmen to present certain certifications to TSA for inspection when so requested
- *Part 1542* contains the regulations for airport security. These airport requirements primarily address access control, law enforcement support, and fingerprint-based criminal-history records checks, among other things.
- *Part 1544* addresses airport operator security for air carriers and commercial operators. Part 1544 requires that the aircraft operator not permit persons to have unauthorized explosives, incendiaries, or weapons when on board an aircraft.
- *Part 1546* provides the rules for foreign air carrier security including the screening of individuals and property, access to cargo, and bomb or air piracy threats.
- *Part 1548* provides the rules for indirect air carriers that operate within the United States, including the acceptance of cargo and security threat assessments.

- *Part 1550* was created to require security programs for both passenger and all-cargo operations using aircraft with a maximum certified takeoff weight of 12,500 pounds or more.

ROLE OF INTELLIGENCE

The comprehensive 9-11 Commission Report details how al-Qaeda was allowed to become a real danger to the United States in the years preceding 2001. The attack was driven by Osama bin Laden, who built a dynamic and lethal terrorist organization over the course of a decade. The Report surprisingly concludes that "the 9-11 attacks were a shock, but they should not have come as a surprise." The terrorists had given plenty of warning that they meant to kill Americans in great numbers. With 20/20 hindsight, it is clear that the 9-11 attacks were able to succeed due to a serious failure of the U.S. intelligence community.

NATIONAL COUNTERTERRORISM CENTER

A major recommendation of the 9-11 Commission was to build a "Unity of Effort" combining all strategic intelligence and operational planning under one office. The *National Counterterrorism Center (NCTC)* was established by Presidential Executive Order 13354 in August 2004. This order was codified into law by the *Intelligence Reform and Terrorism Prevention Act of 2004 (IRTPA)*. The establishment of NCTC implements a key recommendation of the 9-11 Commission as follows:

> *Breaking the older mold of national government organization, this NCTC should be a center for joint operational planning and joint intelligence, staffed by personnel from the various agencies. (9-11 Commission Report, p. 403)*

Today, the NCTC is manned on a 24×7 basis in a modern operations center collocated with the Central Intelligence Agency (CIA) and Federal Bureau of Investigation (FBI) operations centers. It is staffed by more than 500 personnel from over 16 different U.S. departments and agencies. The Director of NCTC has a unique, dual line of reporting: (1) to the President for counterterrorism planning and (2) to the Director of National Intelligence (DNI) regarding intelligence matters. The DNI began operations on April 22, 2005 as another major recommendation of the 9-11 Commission and the IRTPA legislation was implemented on that date. Today, the Director of National Intelligence serves as the single head of the intelligence community, overseeing such major intelligence offices as follows:

- The Central Intelligence Agency
- The Defense Intelligence Agency
- The National Security Agency
- The National Reconnaissance Office

As stated on its Web site, the NCTC has a threefold mission to lead the effort to combat terrorism at home and abroad:

1. Analyzing the threat
2. Sharing information with intelligence partners
3. Integrating all instruments of national power to ensure unity of effort

National Counterterrorism Center analyzes the threat by integrating all counterterrorism intelligence from across the community, producing detailed analytic products such as the following:

- President's Daily Brief
- National Terrorism Bulletin
- Information on the chemical, biological, radiological, and nuclear threats

National Counterterrorism Center shares information with U.S. intelligence agencies by conducting analysis of more than 30 dedicated intelligence networks located under one roof. It routinely makes these counterterrorism products available to the following:

- Intelligence users in 75 U.S. government agencies through the NCTC Interagency Threat Analysis and Coordination Group
- Intelligence users also obtain information by means of a daily secure video teleconference system on a 24×7, 365 days a year basis

National Counterterrorism Center integrates all instruments of national power in the Global War on Terrorism through joint planning and strategic plans such as the following:

- The National Implementation Plan for the War on Terror
- The National Strategy for Aviation Security

DEPARTMENT OF HOMELAND SECURITY

The National Strategy for Aviation Security cited above details the comprehensive U.S. government strategy in this area. The DHS coordinates the operational implementation of this strategy, which is an overarching national plan to optimize aviation security integration on a government-wide basis. Six supporting plans, listed below, have been issued to ensure collaborative interagency effort. (Please see www.dhs.gov for the latest information.)

1. Aviation Transportation System Security Plan (DHS and DOT)
2. Aviation Operational Threat Response Plan (DoD and DoJ)
3. Aviation Transportation System Recovery Plan (DHS and DOT)
4. Air Domain Surveillance and Intelligence Integration Plan (DoD and DNI)
5. Domestic Outreach Plan (DHS and DOT)
6. International Outreach Plan (DOS)

REVIEW OF SECURITY TECHNOLOGIES

To strengthen commercial aviation security, numerous technologies have been fielded and others are under development. The first stage of the deployment of new, advanced security equipment began in 1997 when Congress appropriated $144 million to this end. After the events of September 11, 2001, the implementation plan was sped up, and all airports were required to install baggage and passenger screening equipment by December 2002. TSA began deploying state-of-the-art Advanced Imaging Technology (AIT) in 2007. In March 2010, TSA started deploying AIT units which were purchased under the $1 billion appropriation to TSA, authorized by the American Recovery and Reinvestment Act jobs program brought about by the worldwide recession of 2009–2010.

Protection from the threat of explosives is of particular interest and has been pursued in two general ways: by preventing explosives from reaching the aircraft, such as by using explosives detection technologies, or by mitigating the effects of an explosive by protecting the aircraft from an onboard explosion such as via aircraft hardening and hardened containers. While each of these approaches will be discussed individually, a combination of these two approaches may provide the best protection of commercial aviation. In some cases, technologies can be used for detecting several threats, such as imaging detectors that search for explosives, knives, and firearms.

IMAGING TECHNOLOGIES

Imaging technologies work either by sensing the natural radiation emitted by the human body (millimeter wave) or by exposing subjects to a specific type of radiation and then measuring the radiation reflected by the body (backscatter). These systems can detect metallic weapons or plastic explosives by sensing the differences in reflected radiation between the human body and the weapons or explosives. The screening systems then generate television-like digital images. Operators are trained to identify potential threat objects in these images, often with the assistance of image-enhancing software that highlights unusual features. Figure 13-8 shows a security officer at an airport scrutinizing an image from a baggage screening x-ray system.

FIGURE 13-8 A TSA security screener examining an image at an airport. (*Source: TSA*)

FULL BODY SCAN. Transportation Security Administration uses two types of advanced imaging technology today, millimeter wave and backscatter x-ray technology. *Millimeter-wave scanners* come in two varieties: active and passive. Active scanners predominate the market; passive technology is still under development. Active scanners work much like radar, they direct millimeter wave energy at the passenger and then interpret the reflected energy. Since modern

scanners can display images that reveal private parts of the human anatomy, some privacy objections were raised by the public when awareness of the technology became public. To alleviate the privacy concerns, in February 2011 the TSA began testing a new software system on its AIT machines which eliminates passenger-specific images, and instead, "auto-detects" potential threat items and indicates their location on a generic outline of a person. The generic outline is identical for all passengers. If no potential threat items are detected, an "OK" will appear on the monitor with no outline of the body.

Backscatter *x-ray imaging* is also used for full body scanning by detecting radiation reflected from the passenger. X-ray units used for inspecting carry-on luggage and people employ low-dosage, low-energy radiation. Higher dosage units are used for checked baggage. Older generation units produced images of low quality and poor contrast. Most of the older analog systems have given way to modern digital video amplification and processing systems that produce clearer images and increased contrast ratios. On its Web site, the TSA assures the public that current technologies are safe and meet national health and safety standards. TSA states that the energy projected by millimeter wave technology is thousands of times less than a cell phone transmission. A single scan using only backscatter technology produces exposure equivalent to 2 minutes of flying on a plane.

EXPLOSIVE TRACE DETECTION TECHNOLOGY

Explosive trace detection technologies are based on the direct chemical identification of either particles of explosive material or vapor-containing explosive material. Thus, the presence of a threat object or bomb is inferred from the presence of particulate matter or vapor. The main difference between trace detection and electromagnetic imaging is that in trace detection a sample of the explosive material must be transported to the instrument in concentrations that exceed the detection limit.

Trace detection technologies cannot be used to detect the presence of metallic weapons. All trace detection equipment is regulated by TSR Part 1544.213. The two distinct steps in trace detection are sample collection and chemical identification. Trace detection practices are more commonly used for baggage screening, as opposed to people screening, in aviation security. Some basics of this technology are discussed next.

SAMPLE COLLECTION. Explosive substances can be detected by instrumentation in their vapor or solid form. Initial efforts in the development of trace detection

technology were focused on collecting vapor around the person or baggage. However, because many modern explosives do not readily give off vapor at room temperature, the focus has expanded to include detection of particulates of explosive materials on the skin and other surfaces.

If traces of explosive material are to be detected, they must be concentrated from an air sample or dislodged from a substrate. The air sample, called vapor detection, requires large amounts of air to be collected, from which small amounts of the substances of interest are extracted. The substrate sample, called particle detection, requires pieces of explosive material to be removed from the surface to which they are adhering. Both trace detection approaches have strengths and weaknesses depending on the type of explosive material being sought. Vapor technologies are more effective for detecting explosive materials with high vapor pressures, while particulate technologies are more appropriate for detecting explosive materials with low vapor pressure such as military-style plastic explosives.

Samples can be taken either by having the subject walk through a portal (the *puffer* machine approach) or by passing a hand-wand device over the subject or piece of baggage (the swab approach). Either method may be implemented as a *contact* or *noncontact* technique. In contact portal sampling, passengers walk through a portal by pushing open a door or by rubbing against paddles or brushes. In a noncontact system, an airstream passes over the passengers as they walk through the portal. Hand-wand devices may be used to sample air around the person or to make physical contact. In general, contact methods focus on gathering particulates of explosive material from the hands or clothing of the subject. Noncontact methods may use the airstream to dislodge particles, or they may distill a sample of explosive vapor from the airstream.

Although using a hand-wand device is a potentially efficient sample collection technique, it is more labor-intensive and more time-consuming than collecting samples by using an automated portal. The optimum solution may be to attach a hand-wand device to a portal-based trace detection system as a higher-level surveillance accessory. This is a common technique used with metal detection portals. In trace detection, a single chemical-identification instrument could be served by both the portal and the hand-wand device sample collection mechanisms.

Transportation Security Administration is expanding its use of explosive trace detection, especially using the swab approach. To ensure the health of TSA workers, swabs are disposed of after each use. When tested, the swab is placed inside a fixed or portable machine which analyzes the content for potential

explosive residue. American Recovery and Reinvestment Act funding is also being used to purchase additional explosive trace detection equipment. Figure 13-9 shows a security officer at an airport checking for traces of explosives found on a passenger.

FIGURE 13-9 A security screener checking for traces of explosives. (*Source: TSA*)

EXPLOSIVE DETECTION SYSTEMS (EDSs)

Bulk *explosive detection systems (EDSs)* include any device or system that remotely senses a physical or chemical property (or combination thereof) of an object in an attempt to detect the presence of an explosive concealed in a container (e.g., passenger baggage). Today TSA screens 100% of all baggage placed on an airplane, often covering 2 million passengers processed each day. This equipment must function without causing unreasonable delays, so reliability and throughput are very important.

There have been major improvements in EDS baggage screening technology in recent years. TSA has recognized this trend and has fostered technology improvement through priority funding provided by the *American Recovery and Reinvestment Act*. In fact, a new standard has evolved in this area of *Checked*

Baggage Inspection Systems (CBIS). At present, average in-line, medium speed equipment can inspect around 600 bags per hour. TSA standard for high-volume screening is a throughput of at least 900 bags per hour with a low, false alarm rate.

Companies are meeting this challenge by providing improved image quality and on-screen resolution using three-dimensional (3D) images very similar to the magnetic resonance imaging (MRI) technology used in medical radiology offices today. In-line checked baggage systems of the future will be extremely efficient, able to achieve a throughput of over 1,000 bags per hour, and easier to maintain with built-in diagnostics tools. These high-speed screening systems will also be upgradable and allow airports to increase baggage handling capability without major capital investments.

METAL DETECTORS

Screening procedures currently used in U.S. airports, at least during routine operations, involve metal detection portals for screening passengers and x-ray imaging systems for screening hand-carried baggage. Metal detection devices impose a time-varying magnetic field in the space within the portal that induces eddy currents in metallic or ferromagnetic objects passing through that space. Various methods are used to detect these eddy currents, and when they exceed a preset level, an audible or visual alarm goes off, and an operator intervenes to ascertain the presence or absence of a dangerous object or weapon. The effectiveness of this security screening system depends not only on the performance of the equipment, but also on the performance of the personnel operating the equipment and resolving the alarms.

Metal detectors vary from portals to handheld systems depending on the application and size of the airport. Most passengers are required to pass through a portal-type metal detector, but a more scrutinized search could be conducted with a handheld or portable metal detector. Metal detectors are not as effective as other systems, and their deficiency lies in their inability to catch all forms of dangerous weapons. Their greatest weakness is that they do not detect metals incapable of being magnetized. Newer-generation metal detectors can search for ferrous or nonferrous objects. Metal detectors are used broadly around all the airports and are one of the most important sources of security.

An important advance in metal detectors is the multizone concept. Through a multizone approach for portal-type metal detectors, sensitivity can be assigned to specific areas of the body zones that the metal detector would scan. Each zone has its own sensitivity adjustment. This permits the detection response of each

zone to be independently adjusted. The horizontal zone corresponding to the foot region of the body can be made more or less sensitive than the waist region or vice versa. Use of metal detectors in airport security is regulated by TSA under its Part 1544.209. Figure 13-10 shows a sample of some of the loaded firearms that have been detected and confiscated during airport security screening.

FIGURE 13-10 Some of the many weapons and ammunition caught by security screeners at airports. (*Source: TSA*)

BIOMETRICS AND FUTURE CHECKPOINT SYSTEMS

The term *biometrics* refers to the emerging field of technology devoted to identifying individuals by using biological traits such as those based on retinal or iris scanning, fingerprints, or face recognition. *Biometric technology* is defined as the automated use of physiological or behavioral characteristics to determine or verify identity. This technology has been used in place of passwords by some government agencies but increasingly finds uses in a wide range of security applications, such as preventing unauthorized employees from gaining access to certain areas and assets. Another use is to quickly identify low-risk users, such as prescreened airport passengers, so that security personnel can focus on the much smaller category of “high-risk” passengers.

Biometric systems are basically of two types: verification and recognition. By measuring a physical feature or repeatable action of the individual, we establish

measuring a physical feature or repeatable action of the individual, we establish a biometric identification. Verification systems require that the individual seeking access have some sort of identification, such as a smart e-card, that is then matched with some physical characteristic of that person to make the verification. A reference measurement of the biometric is obtained when the individual is programmed into the device.

In addition to using biometric contractors, TSA has chosen to focus on the 9-11 Commission recommendation that the government take over the No Fly Watch List system. This is the careful computer screening of passenger information by comparing names to the federal government intelligence watch lists. The Intelligence Reform and Terrorist Prevention Act of 2004 (IRTPA) codified this recommendation so that as of November 1, 2010, the new TSA Secure Flight Program requires airlines to collect and transmit the following Secure Flight passenger data to TSA:

- Name as it appears on government issued ID when traveling
- Date of birth
- Gender
- Redress number (this is a special number given to passengers who have resolved denied boarding problems with the TSA to prevent future delays as a misidentified passenger)

Many U.S. airports are now approved for Global Entry and TSA pre-check screening. Global Entry is a program of the U.S. Customs and Border Protection service that allows pre-approved, low-risk travelers to receive expedited clearance upon arrival into the United States. Passengers can enroll in these plans online and must also visit a government office for a background check and fingerprinting. In this expedited personal screening process, passengers do not have to remove shoes, laptop computers, small personal liquid containers, belts, or light jackets. Passengers who register for these programs are usually rewarded with a quick clearance through TSA security checkpoints.

Strengthening Aircraft and Baggage Containers

Another approach to aviation security is to try to strengthen aircraft frames and to plan redundancies in vital systems such as controls, electrical systems, and hydraulics to mitigate the effects of bomb blasts in flight. A further alternative is to use hardened baggage containers that can control the effects of bomb blasts in checked baggage.

Retrofitting is difficult. It is easier and more practical to incorporate such design measures during the design stage of the aircraft. The FAA has engaged in extensive studies with military experts and airframe manufacturers to learn how aircraft fail due to explosions in flight and to discover measures to increase chances of aircraft survival. Explosive tests have been carried out by the FAA in the United States and in the United Kingdom to check calculations.

Using *hardened unit load devices (HULDs)* to protect aircraft from explosive attacks is not a new concept. Airlines that operate in high-risk areas of the world have been using custom-built containers. Because these containers are much too heavy for general use, only one or two are used per aircraft for carrying select items. However, new advances in technology and the need for increased security after the terrorist attacks of 2001 have resulted in greater use of these containers. Even though a certified HULD is now available, the FAA has not developed a deployment plan for airline service. The idea of replacing all existing containers with HULDs has been abandoned because of its impracticality in terms of weight, cost, and operational factors.

COCKPIT DOOR REINFORCEMENT

On January 10, 2002, the FAA published new standards to protect cockpits from intrusion, small-arms fire, and fragmentation devices, such as grenades. The rule required U.S. airline operators to install reinforced doors by April 9, 2003. Congress appropriated $97 million to help the airlines defray the cost of cockpit door replacement. Current cockpit door regulations and security standards are found in 14 CFR Section 25.795. This single enhancement has proven to be a very successful measure to counter cockpit invasions.

CYBERSECURITY

Cyberspace is the environment in which communication occurs between and over computer networks. Such networks are vulnerable to both physical and remote cyberattacks, and the protection against such acts constitutes *cybersecurity*. It can be particularly challenging to defend against such attacks since terrorists can operate from anywhere in the world and can use inherent weaknesses in the numerous complex linkages between cyberspace and physical systems. Given that software and information technology are critical components of modern commercial aviation, to include the airport and air traffic systems, a new battlefront has been opened by terrorists in these areas. According to the U.S. Government Accountability Office report in 2015, cyberattacks have grown

tenfold recently. In 2006 there were only 5,503 such incidents reported, compared to 60,753 in 2013.

With the development of NextGen technologies underway, as described in Chapter 10, experts say there are multiple cybersecurity vulnerabilities in the new system. Whenever technology is increasingly automated, it needs to be integrated with the same degree of security. However, NextGen technologies still have significant security-control weaknesses that will be a threat to ensuring safe and uninterrupted operations. Replacing a radar-based air traffic control system with one that connects controllers and aircraft via data and satellite links will create an environment that is much more sensitive to a cyberattack. One NextGen technology endangered by this is ADS-B, which allows aircraft to determine its position and broadcast that information to other aircraft and ground controllers through satellite. The security issue here is that ADS-B is publicly accessible using real-time computer applications that have flight tracking. It could be easy for a hacker to create a fictitious aircraft in the system, which could confuse pilots and air traffic controllers.

NextGen technology is not the only weak link in the aviation sector. Boeing 787 and Airbus 380 electronic-enabled aircraft, also known as e-Enabled, will also raise security concerns. The systems in these planes are networked in real-time to ground stations and receive and transmit data that can influence navigation, maintenance performance, and airplane health back to stakeholders. This gives airplane power-plant manufacturers direct access to the engines while in flight for health monitoring and diagnoses. Everything is interconnected, from the transportation system to plane diagnostic entities. Unfortunately, manufacturers often do not perform sufficient cybersecurity testing prior to issuing an airworthiness certificate, which is the document that authorizes a plane to fly. That shortfall is problematic because planes are becoming less manually controlled and more technology based. However, there does not seem to be a regulatory remedy in the future due to the complexity of the issue and the required financial resources.

Although the FAA, European Aviation Safety Agency (EASA), and Transport Canada rely on the RTCA certification, DO-178C for guidance on aviation software, the document does not specifically address airborne network and data security. This shortfall has the potential to create nonstandardized and potentially unfair agreements between various users and the regulatory agencies for an acceptable process for the compliance of safe, secure, and efficient network design and operations.

Thus, in an effort to strengthen our fight against cyberattacks, we must focus

on two measures. First, the industry must adapt its technology. Companies must take into account the whole threat life cycle, which includes building the best protection and recognizing threats as the environment changes. For example, Boeing took proactive measures against threats by requesting the FAA to issue special conditions for its Model 777-200, -300, and -300ER after detecting vulnerabilities in the avionics systems. Another example is the use of threat modeling, a technique that assists software engineers in identifying and documenting potential security threats. Threat modeling provides development teams with a way of finding strengths and weaknesses in software applications through visual representations of the system.

The second measure to counter cyberattacks is through increasing cybersecurity awareness. Businesses must be willing to share information with each other, as hackers may target the same types of companies and infrastructure. Additionally, society must grow the pool of cybersecurity professionals. According to a 2015 analysis by the Bureau of Labor Statistics, there are more than 200,000 cybersecurity jobs unfilled, the demand is expected to increase to a 1.5 million shortage of these professionals by 2020.

Security for commercial aviation now means not only protecting people and property but also safeguarding information and data against unauthorized persons and systems. As we move into the future of flight, we must consider a new set of questions to ensure safety and security objectives are being met. We will begin to see discourse shift to discuss the following topics:

- Who can access the system?
- How can the system be accessed?
- What can be attacked?
- What needs to be protected?

ASRS EXAMPLES

There are several measures put in place by airlines to protect the security of passengers. Below are a few examples from the Aviation Safety Reporting System that demonstrate aviation professionals’ tenacity in maintaining security through their adherence to company policies. The first report is from a pilot who is reporting a problem with boarding. The second report is from a cabin crewmember reporting on a passenger screening breach.

Security Procedures

Title: Compromised security resulting from procedural deviations.

During the initial boarding process, I heard my Flight Attendant trying to keep passengers off of the airplane until a bag was removed from outside the aircraft (we had coordinated with the gate agents ahead of time to have the passengers sent out 25 minutes prior to departure per standard policy). However, during the boarding process, we noticed a checked bag sitting forward of the wing on the green gate-checked bag cart now with the other passengers' bags. The passengers were dropping their green gate–checked bags off alongside this white checked bag (all on the same cart). After hearing my Flight Attendant, I immediately left the flight deck and stopped the passengers from boarding the plane. I had the passengers already on the plane deplaned and sent back inside. I advised Operations we had a white checked bag in the same proximity as passengers and that we needed to perform a full security search of the aircraft (which my crew performed and documented). I contacted Dispatch who contacted Ops. Ops sent out a GSC [Ground Security Coordinator] to ask why we were delaying the flight. After all of the coordination and security search, we were allowed to continue the flight.

A checked bag should never be placed around passengers. We were repeatedly told over and over again by the rampers (and the GSC) that placing white checked bags in front of the wing is commonplace when a baggage cart is not around. We were then chastised for delaying the flight and were told that "This is how we do things over at the X and Y terminals. We always put white tags on bags at the gate." I had a VERY difficult time convincing the GSC that this bag did NOT come from a passenger at the gate (it was a checked bag, not a gate-checked bag that was white-tagged). My Flight Attendant tried to explain our Company security policies to the GSC, but the GSC was again saying this is how they did things at "X and Y." We had a very difficult time communicating with the ground personnel who were convinced they were doing everything right.

The station rampers NEED to know security procedures so that the flight crew can be on the same page as the rampers. The focus is on on-time performance way too much, this time at the risk of security. After coordinating with Dispatch and Ops, we were told that the bag was from a connecting flight and not placed on the concrete so that it didn't get wet. Unfortunately, we had numerous bags that were in fact placed on the concrete behind the wing, so that was a poor excuse. What is more, I took a picture of the very dry concrete immediately after being told this. If a baggage cart needs to be present so this does not take place in the future, then get a baggage cart. If security procedures need to be taught to ground personnel, then teach security. If on-time performance needs to be secondary to security (as it should be), then teach safety first. What is more, after we completed our turn, I was contacted by Dispatch saying that we as the flight crew were now being blamed for the delayed flight. We were told that the ground personnel were now saying that the checked bag was removed from the cart before ANY passengers were boarded which is a bold lie. When I left the flight deck (with a few passengers already onboard), I went immediately to the white checked bag on the baggage cart and inquired about what it was and where it came from. So if honesty needs to be taught, then teach honesty.

Questions for the reader: Please explain why the flight crew was so concerned about passengers possibly being able to access a checked bag. How did employee ethics impact this scenario and future scenarios?

Cabin Crew

Title: Security breach from early boarding of plane.

Narrative 1:

Yesterday at XA:58 was going thru security when a passenger behind me stated, "why were we late since they are boarding," in which I replied impossible he must have mistaken us for the cancelled flight from the previous night and they sent the passengers to an unscheduled flight for XA:30 departure. I stated that he must have been slightly delayed since our flight has a XC:00 departure with an XB:00 sign in. When my crew and I arrived at the gate we noticed few people in gate area and many boarding our flight! We were in disbelief since it was not even XB:00 and boarding time was not till XB:15! When we approached the [gate] agents they were in shock and did not know how to respond to us. We told them that this was a huge security breach and refused to board until they deplaned all passengers and do another security sweep. They did as requested and we boarded, did our equipment check and were able to board and depart on time.

Narrative 2:

We arrived at the gate approximately XA:57 and [are] met by the Ground Manager informing us they allowed passengers to board without the entire flight crew (pilots and flight attendants). I was shocked and told her that was a serious breach of security. Our Lead Flight Attendant and the rest of the crew refused to step on board the plane till proper security procedure be corrected. We were looking for the Captain, not aware he boarded the plane. After a few minutes the Captain deplaned and came back to the gate where he basically wanted us to go ahead and continue the rest of the boarding process. He said majority of the passengers are already on board and he wanted us to continue. I told him I did not want to violate security procedure with another violation because he said so. We tried to explain to him we also need few minutes to check our emergency equipment and other security procedure. Moreover we are not sure those passengers that boarded had been security cleared. Our Lead FA and the other 2 FAs explained to Captain as well to please do it right. We told him we need to deplane everybody and do another security sweep. If we do it right immediately we can manage to board all and still leave on time. At the end it was corrected and security sweep was accomplished after deplaning all the passengers. I honestly have no idea why it happened. This was my first experience of a security violation in my many years of flying. Gate agents and ground crew need to be retrained on security procedures. Most importantly Captain must be on top of these and have it corrected *as soon as possible instead of persuading flight attendants to continue a serious security violation that can easily be corrected in the first place*.

Narrative 3:

When crew arrived airport personnel had already begun boarding flight when there were no crew members onboard the airplane. As a matter of fact, they began boarding before we were even on airport property.

Question for the reader: Please discuss why do you think all three flight attendants submitted reports for this incident instead of just relying on one flight attendant to report the situation on behalf of all of the cabin crew.

CONCLUSION

Figure 13-11 shows the large area consumed by the passenger screening area for one of the terminals at Barcelona International Airport in Spain. The enormous costs incurred to implement modern security technology illustrates the acute

nature of the threat facing commercial aviation operations. High-technology detection methods can yield results, but it is clear that these results are expensive and are not perfect. Often, a small increase in security is achieved at very great expense. Furthermore, the cost is not just one of capital asset acquisition. There is also the matter of operations and maintenance.

FIGURE 13-11 Passenger screening area for Barcelona's Terminal T1. (*Source: Wikimedia Commons*)

Although technology has its place in the overall security scheme, it is no panacea for air transportation security concerns. On the personnel side, greater attention needs to be paid to security staff recruitment, training, and procedures. Security professionals play a critical role and are the ones who interpret the results of the technological analyses. The technology itself needs to be designed from the start with cybersecurity in mind, and upgrades need to be continuously performed to guard against the latest types of cyberattacks.

Until the TSA was established and took over security screening, many security personnel were low-paid workers who lacked the required training. The profession was plagued by questions of morale, turnover, stress, and ineffectiveness. The FAA insiders had criticized security personnel as being inadequate. The ATA responded by developing standards that called for better selection, improved work conditions, and rewards for effective security personnel. In addition, many airlines upgraded their personnel screening processes. Nevertheless, despite new training requirements, the process remained uneven. The length of training was too short, and the required contents to be covered were loosely defined. When the TSA took over this function in

2001, conditions improved for security personnel in terms of pay, training, and other benefits. This has led to improved levels of security at airports.

Another consistent problem through the years has been the screening of airport workers. Airports are like cities in that they require employees to work a large variety of vocations ranging from salespeople to mechanics to cleaners. Because this diversity of workers provides terrorists with numerous opportunities for infiltrating airport security zones, the FAA requires background checks, the review of previous employment records, and the wearing of special identification badges. Despite these efforts, these measures do not guarantee security. Terrorists can forge badges, although forging computerized badges is a far more difficult task, requiring insider collaboration or access to the computerized database and badge process. With the landscape of aviation technology changing, terrorists now have a new opportunity to exploit weaknesses and loopholes in the system. Instead of targeting airports and property, they can interfere with software and communication from remote locations.

In addition, a technology solution alone suffers from problems defined by two related axioms. The first is that airport security is very site-specific. The thought being that what works well and inexpensively in one place is not necessarily a sound approach in some other place. The second axiom is political: regulators seldom recognize the real-world needs of security. No matter how well conceived a security regulation may be, it is not likely to have anticipated the kinds of problems that may actually arise.

An important concluding point is that, in spite of all that have been accomplished to ensure the security of the traveling public, the terrorist, in one sense, always has the upper hand. While we must protect every element of the transportation system at all times (not just aviation), the terrorist always has the advantage of being the only one who knows the time, the place, and the method of the next attack. Stay vigilant!

KEY TERMS

Anti-hijacking or Air Transportation Security Act of 1974
Aviation and Transportation Security Act of 2001
Aviation Security Improvement Act of 1990
Bag Matching
Biometrics
Checked Baggage Inspection Systems (CBIS)

Cybersecurity
Department of Homeland Security (DHS)
Explosive Detection Systems (EDSs)
Explosive Trace Detection Technology
Hardened Unit Load Device (HULD)
ICAO Security Manual (Doc 8973)
Intelligence Reform and Terrorism Prevention Act of 2004 (IRTPA)
International Civil Aviation Organization (ICAO) Annex 17
Metal Detectors
Millimeter-Wave Scanners
National Counterterrorism Center (NCTC)
Security Management System (SeMS)
Security versus Safety
The 9-11 Commission
The Air Marshal Program
The Homeland Security Act
Transportation Security Administration (TSA)
White House Commission on Aviation Safety and Security (the Gore Commission)
X-ray Imaging

REVIEW QUESTIONS

1. What is the difference between security and safety?
2. Provide three examples of different categories of attacks on civil aviation.
3. Describe the international response to terrorism by ICAO and the world community.
4. What is the Air Marshal Program and why was it instituted?
5. Discuss the hijacking era. When did it end?
6. What was the biggest security lesson learned from the Pan Am Flight 103 tragedy?
7. Use an example to explain the concept of *redundant technical measures* in security.
8. Discuss the role and functions of the Transportation Security Administration (TSA).

9. What was the reason for the 9-11 Commission? What impact did its recommendations have on the U.S. intelligence community?
10. Explain the operation of the National Counterterrorism Center (NCTC).
11. Discuss some of the problems encountered in the gathering and analysis of intelligence for security purposes.
12. Give an example of four different security devices used to prevent weapons and explosives from entering an aircraft and explain the workings of these devices.

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CHAPTER FOURTEEN

THE FUTURE OF COMMERCIAL AVIATION SAFETY

LEARNING OBJECTIVES

After completing this chapter, you should be able to

- Depict the general areas presenting challenges and opportunities to commercial aviation safety in the 21st century.
- Discuss the need to modernize air traffic services and technology in order to reduce accident rates and increase efficiency.
- Provide examples of unresolved and emerging problems facing the commercial aviation sector that threaten to impact aviation safety in the first half of the 21st century.
- Explain several technological areas requiring attention by aircraft designers to reduce accidents and serious incidents in the 21st century.
- Describe the difficulties associated with ensuring that key flight crews are healthy psychologically.
- List some of the emerging challenges faced by practitioners and researchers of Safety Management Systems.

INTRODUCTION

This chapter explores the expected major challenges facing the commercial aviation industry in the first half of the 21st century, as detected through new factors present in accidents, serious incidents, and proposed by academic researchers. Several of the previously covered areas in the book will continue receiving significant attention by aviation professionals because many risks have not been eliminated and must be continuously managed going into the future. The new concepts exposed in this chapter are not meant to be an exhaustive coverage of emerging safety areas, and as the years pass, new areas of attention will surely emerge. That is the nature of safety. As the Nobel Prize–winning Danish atomic physicist, Niels Bohr, once humorously quipped, “Prediction is very difficult, especially of the future.” Nevertheless, the areas covered provide an overview of different conditions that are receiving increased attention by

aviation safety professionals at the time of this book’s printing.

AIR TRAFFIC MANAGEMENT

There is a relatively well-known quote, sometimes attributed to the American author Mark Twain that says, “Buy land, they’re not making any more.” A similar sentiment can apply to airspace since we do not have the ability to make more area in which to fit aircraft. What we can do is use what we have more efficiently. There are increased demands to integrate new types of vehicles into the airspace that has mostly been used by traditional commercial and private aircraft.

The significant increases in commercial air travel strain the planet’s airspace, especially when coupled with the explosive growth of unmanned aircraft systems (aka “drones”). The airspace will face further strain in future years as new suborbital space flight vehicles start ascending and descending through the lower atmosphere in a short amount of time. When we venture away from airports and, particularly, out over large bodies of water that often lack radar coverage, the challenge is not as much traffic congestion as it is tracking flights. When flights go missing it can take years to find the aircraft that have experienced an accident, if we find the missing aircraft at all.

AIRSPACE UTILIZATION

Much of the globe increasingly faces a daunting aviation safety challenge as the century develops. The seemingly incessant increase in the demand for air transportation will mean that more and more aircraft will fill the skies. Simultaneously, the traveling public is growing more demanding of safety. The overriding challenge is therefore how to simultaneously enhance airspace capacity, particularly in the airport areas, while decreasing the commercial aviation accident rate.

Currently, most U.S. airspace is managed by air traffic controllers who use radar as a key tool for managing aircraft flow. The radar sweeps the area it covers with a radio wave and recognizes flying objects. Typically, it takes a radar dish 12 seconds to rotate. Even though it is a reliable method, it is expensive and does not give information in real time since controllers must wait 12 seconds for the position updates. To cope with the time gap for new information, controllers keep wider separation between aircraft. This decreases the capacity of the airspace. The aviation industry and the governments of many countries are looking for new, safer ways to increase the amount of planes in the

countries are looking for new, safer ways to increase the amount of planes in the sky.

New operational procedures and technology have been introduced systematically and slowly. Safety is a critical concern of the industry, so the challenge must be approached with caution. Proposed changes undergo serious consideration and testing prior to being implemented. The field is very innovative, but often the technological advancements in the aircraft have outpaced those for air traffic control. In some cases, planes built during the 21st century are using routes with radar stations from the 1940s and 1950s.

For the traffic growth to continue safely, the air traffic management system must also undergo changes. This includes changing the system so that it centers on the performance of flight itself. Controllers would manage the airspace to provide optimal use rather than control the route of each flight. The benefit is that controllers would be able to handle more aircraft at any one time while reducing delays and improving safety.

North America remains the busiest region in the world for air traffic. The Federal Aviation Administration (FAA) is the body that governs how the United States will implement new policies and technologies for increasing the safety of airspace utilization. The FAA aims to incorporate technologies that will make air transportation more safe and efficient. Some of these include *NextGen* programs such as satellite surveillance, *required navigation performance (RNP)*, and the *Automatic Dependent Surveillance—Broadcast (ADS-B)* system.

NextGen is the United States' new national airspace system set to be in place by 2025. It aims to transform the air traffic control system from a radar-based system to a satellite-based one with GPS. The program's priorities include multiple runway operations, nonvoice data communication, performance-based navigation, surface operations, and data sharing. One aspect all of these priorities have in common is that ultimately they will make the ground and the airspace safer places.

Satellite surveillance is technology that has recently emerged to help support air traffic navigation. With greater visibility of what is going on in the sky at all times, air traffic controllers can utilize more of the available airspace for operations. Aircraft can also fly closer together, which increases capacity significantly without affecting safety. Further reductions in spacing may be obtained through more accurate modeling and detection of wake turbulence, among other factors.

Required navigation performance is a concept that stems from satellite surveillance and is helping improve the safety of airspace utilization. It allows planes to fly precise routes without having to rely on ground-based radio-

navigational signals. One advantage is that RNP allows pilots to land in hazardous weather conditions that might otherwise require holding, diversion, or even cancellations. Its precision and reliability ultimately can help air traffic controllers to minimize delayed flights and reduce traffic congestion (Figure 14-1).

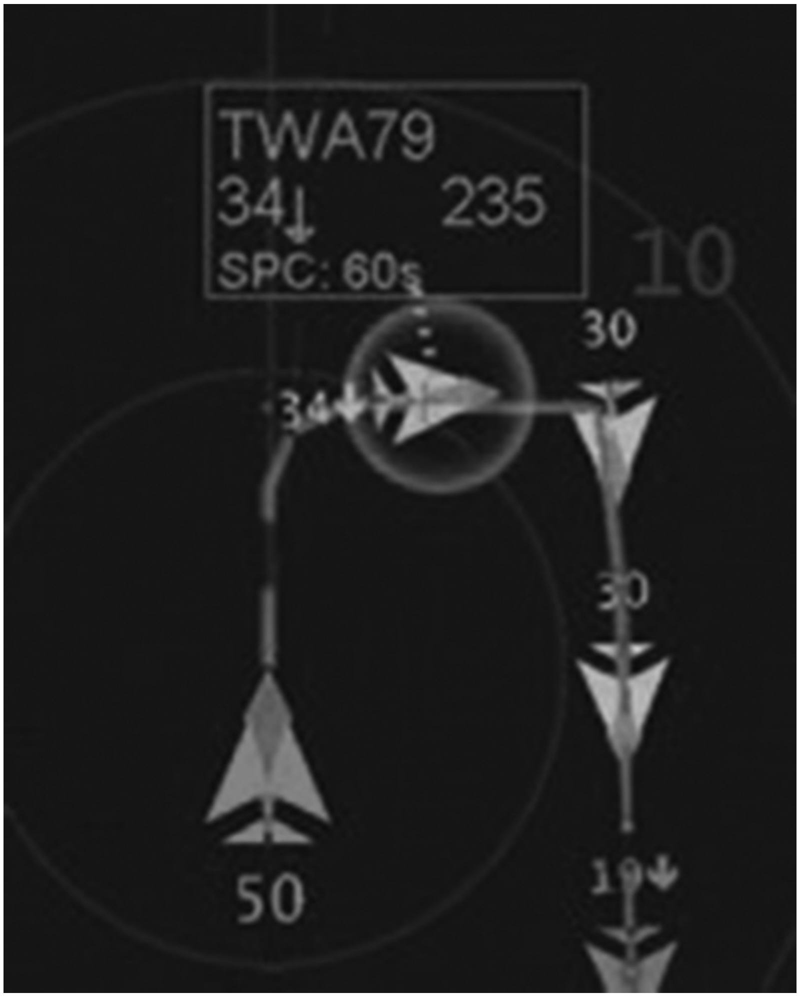

FIGURE 14-1 Sample NextGen cockpit display function under development by NASA that allows pilots to self-regulate spacing from other traffic during arrival at an airport. (*Source: Authors*)

Another flexible airspace and flight operations tool that will help improve safety in the skies is ADS-B. It pairs the satellite navigation system with a network of receivers that are on the ground. The result is enhanced oversight of aircraft position in the sky, an advantage over radar, which only locates an aircraft when it sweeps the area within its range. By using ADS-B, air traffic controllers can reduce aircraft separation, allowing for more efficient routes and increased airspace capacity.

Unmanned Aircraft Systems (UAS)

In addition to expected increases in traditional commercial air traffic, worldwide airspace is under growing pressure by a new type of user. An *unmanned aircraft system (UAS)*, sometimes called a “drone” by the public, is an aircraft without a human pilot onboard—instead, the UAS is controlled by an operator on the ground. The growth of UAS has exploded as users purchase them for commercial and recreational purposes. Other terms used to describe these vehicles include unmanned aerial vehicles (UAV) or remotely piloted aircraft (RPA). As they become more common in the sky, UAS are proving to threaten the safety of traditional aircraft operating in the airspace. Chapter 10 contains further information on this airspace threat, and the reader is encouraged to consult the Internet for the latest information in this rapidly changing area (see www.faa.gov/UAS/).

Although there has yet to be a confirmed midair collision between a UAS and a piloted aircraft in the United States, it is just a matter of time until it occurs. Outside of the United States, the French government agency in charge of accident investigation, the Bureau d’Enquêtes et d’Analyses, reported that on February 19, 2016 a UAS came within 16 feet of impacting an Air France A320 carrying 150 people which was arriving in Paris from Barcelona. The pilot had to disconnect the autopilot and take evasive action to prevent the collision. Furthermore, actual collisions have already occurred in other countries. Many close calls have been near airports. In a number of these cases, the event happened within 5 miles of an airport and at altitudes higher than 400 feet, meaning that UAS obviously can operate far into the airspace that is regularly used by commercial aircraft.

Several challenges are presented when trying to prevent such a hazard. Many of the operators of small UAS have no aviation background and are oblivious to the legal requirements for operating in controlled airspace. It proves very challenging even locating the operators, who could be just about anyone in a private residence operating a small UAS out of their backyard.

The damage a UAS can cause to an aircraft can be quite significant. Both academia and industry have started to research the impacts a collision between the two types of aircraft may have. Currently, aircraft engine manufacturers test their designs against bird strikes but have not taken UAS into consideration. Recent published studies show that a UAS encounter could cause critical damage, including breaking the glass of a cockpit, fracturing helicopter blades, and destroying jet engines. UAS come in varying shapes and sizes. Figure 14-2 shows what most of the general public associate with UAS, but Figure 14-3

serves to caution us that some vehicles can actually be imposingly large.

FIGURE 14-2 A seemingly innocent UAS poses a serious midair collision threat. (*Source: NOAA*)

FIGURE 14-3 Although many think of them as small toys, UAS come in all shapes and sizes. (*Source: USAF*)

To prevent such mishaps and advise the public about UAS safety, the FAA and industry groups have launched an education campaign titled *Know Before You Fly*. Since UAS can jeopardize airspace safety in some situations, the FAA has deemed certain places as *no drone zones* without prior authorization. These areas include, for example, airport control zones, U.S. military bases, U.S. national parks, and near the White House in Washington, D.C. To learn more about FAA current UAS regulations, please refer to FAR Part 107 and the FAA Web site.

COMMERCIAL SPACE VEHICLES

Space tourism used to be a dream of many. However, every day we get closer and closer to making the dream a reality through the commercial space flight industry. In addition to space tourism, aerospace companies are developing vehicles designed for suborbital spaceflight to perform science missions that study the atmosphere, astronomy, and global climate change. In some cases, the

study the atmosphere, astronomy, and global climate change. In some cases, the spacecraft are designed to depart from and arrive at commercial airfields in the same way that traditional aircraft use runways.

The vehicles may feature rocket-powered climbs up to 350,000 feet that result in extremely high rates of climb through all the levels of the airspace and then descend back minutes later after reaching their peak altitude. With such an operation, though, comes the challenge of safely integrating such unusual air vehicles into the air traffic control system. An increase in space operations combined with continued growth in air traffic operations could place a huge demand on the airspace system and air traffic control. Figure 14-4 depicts the simulator for a suborbital space flight vehicle, showing a mission specialist in a pressure suit preparing for takeoff to perform a mesospheric imaging science mission.

FIGURE 14-4 A mission specialist in a suborbital space flight simulator prepares for a science flight from a commercial airport. (*Source: Authors*)

The U.S. space program today includes three sectors: civil, military, and commercial. The Office of Commercial Space Transportation (AST) is the division of the FAA whose mission is to ensure the protection of the public, property, and national security during commercial launch and reentry activities. It also aims to encourage, facilitate, and promote U.S. commercial space

It also aims to encourage, facilitate, and promote U.S. commercial space transportation.

To accommodate the addition of commercial space traffic into the national airspace, the FAA has developed a concept of operations called *Space and Air Traffic Management System (SATMS)*. It will play a pivotal role in providing safe access to all users of the airspace. This aims to seamlessly integrate space vehicles traveling to and from space by developing new space and air traffic management tools. Together, these tools will provide enhanced communications, navigation, and surveillance (CNS) services. A major goal will be to generate methods and procedures to reduce the amount of airspace that is restricted for each launch and the amount of time that space will be needed. In turn, this would accommodate regular air traffic without disrupting the space mission and compromising safety.

A part of the SATMS is the decision support tool (DST). The tool is a software and computing system the FAA is currently designing to facilitate air traffic controllers' management of airspace restrictions and to reduce risks to aircraft from space operations. The tool would have two modes: planning and real time. In the planning mode, the DST would identify the airspace restriction requirements, potential impacts on other airspace users, and options alleviating those impacts. The real-time mode would show the space vehicle's route and help air traffic controllers to maintain a safe separation if emergencies occur. Ultimately, the SATMS DST would allow decision makers to make informed choices for reducing collision risks in the airspace.

Challenges currently exist that prevent the SATMS DST from being fully integrated. One obstacle is validation. Extensive verification testing will be mandatory throughout each phase of design and deployment. Second, the DST must be flexible enough to receive data from many types of vehicles and operators and to provide output information for other parties such as the airlines, military, NASA, and future spaceport and range operators.

Each space mission will have a set of unique requirements that will shape the airspace integration process. As a result, it will require its own strategy. Currently, there is a list of airspace management strategies that include the following:

- Minimizing the duration of the launch and reentry operation's window
- Moving the operating window away from peak traffic times
- Altering the launch or reentry trajectory to avoid placing airspace restrictions in congested airspace

- Negotiating special use airspace so that reserved airspace can be used during the operation to reduce reroute mileage of affected aircraft

One obvious risk of operating traditional aircraft in the same airspace as the comparatively much faster space vehicles is collision. Space vehicles are expected to pass through the vertical layers of airspace quite quickly as they climb to space where payloads can be employed, science samples collected, and tourists awed. Such vehicles could potentially climb through the upper bound of the national airspace system, which is 60,000 feet, in 2 to 3 minutes. Therefore, these operations would be confined to a small region of airspace for a short period of time. One option is the use of *space transition corridors (STCs)* to safely separate traffic. STCs would be designated airspace areas that would be issued and withdrawn as necessary to maximize safety while minimizing the impact to air traffic. An STC would remain in place shortly prior to the flight and removed once the mission had been completed. During the flight, air traffic control would watch the space for weather and traffic conditions and remain on guard for responding to an accident that could affect the safety of the area. Figure 14-5 shows a potential standard profile for certain types of suborbital space flight vehicles, which may ascend to space and descend for landing at a single operating location all in less than 30 minutes.

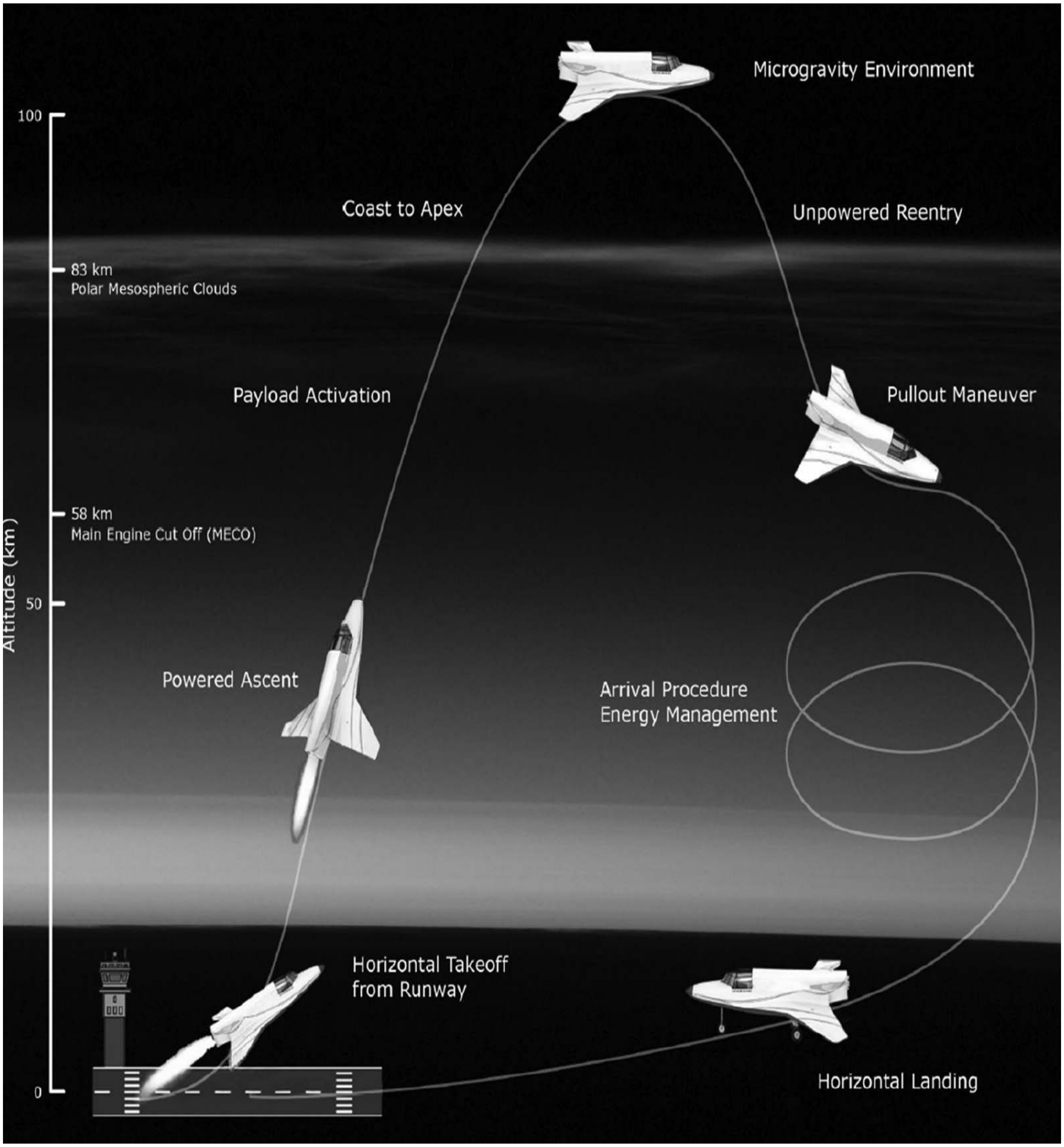

FIGURE 14-5 This profile shows a future suborbital space flight from a conventional airfield. New vehicles will climb quickly into space and then return in less than 30 minutes. (*Source: Authors*)

Although STCs may greatly reduce the risk of a midair collision between space vehicles and conventional aircraft, STCs may prove highly inefficient if spacecraft traffic increases. There are hopes that the commercial spaceflight industry will grow rapidly and also a strong possibility that vehicles will use the same airspace as traditional commercial aircraft. Some plans call for commercial spacecraft to operate out of conventional airfields several times a day per

spacecraft to operate out of conventional airfields several times a day per vehicle. If several such vehicles operate with such high frequencies from the same airfield, it is conceivable that there could be dozens of fast climbs and descents through the airspace overlying an airfield in a single day. Reserving such airspace exclusively for space vehicles could potentially paralyze commercial aviation traffic in the area, so innovative technology and procedures will have to be developed to integrate the spacecraft with the aircraft. Research is currently underway to determine the feasibility of using newly developed technology onboard suborbital space vehicles to allow their pilots to provide their own separation from traditional commercial aircraft, possibly by relying on ADS-B and traffic deconfliction algorithms.

Hazards could also arise if commercial spacecraft experience catastrophic inflight breakups that spray underlying areas with falling debris. For example, the Space Shuttle *Columbia* in 2003 broke apart during reentry, producing a large cloud of falling debris, much of which could have severely damaged or destroyed an aircraft on impact. Models have shown that a piece of a space vehicle debris less than one pound in weight could puncture the wing or cabin of aircraft cruising underneath. Figure 14-6 depicts one of the major pieces of a Virgin Galactic suborbital space vehicle that came apart in the air and crashed to the ground in California in 2014, killing the copilot and severely injuring the pilot.

FIGURE 14-6 The NTSB investigates the fatal Virgin Galactic Spaceship II accident. (*Source: NTSB*)

OCEANIC TRACKING

The flying public often observes how unimaginable it is that in the 21st century we still lose commercial aircraft in the middle of a flight during overseas journeys. In fact, it is something that the aviation community has dealt with since the first transoceanic flight. In 2009 Air France Flight 447, an Airbus 330, disappeared over the Atlantic Ocean, and it took considerable time to find parts of the wreckage. Figure 14-7 shows recovery crews working with a large piece of wreckage in the ocean. The passenger flight was operating from Rio de Janeiro to Paris. All 228 occupants of the aircraft perished.

FIGURE 14-7 Recovery operations for the wreckage of Air France Flight 447. A surface and aerial search was launched until wreckage was spotted by the Brazilian Air Force in the Atlantic Ocean. (*Source: Bureau d'Enquêtes et d'Analyses*)

In 2014, Indonesia AirAsia Flight 8501, an Airbus 320, went missing over the Java Sea for a period of time and was found to have crashed, killing all 155 passengers and 7 crew on board. Also in 2014, Malaysia Flight 370, a Boeing 777, disappeared and could not be found to date. All 227 passengers and 12 crewmembers were presumed dead. Currently, the aviation community is considering short-term and long-term steps to improve aircraft tracking in non-radar areas.

Although many commercial airline passengers probably expect that their flight is being tracked on radar by air traffic control, significant amounts of airspace remain out of radar coverage. In areas such as the North Pole and South Pole, oceanic airspace, and parts of Africa, Asia, and South America, pilots must use radio or satellite communications to update their location to air traffic control. ICAO requires that, at minimum, aircraft have a working two-way radio to communicate with air traffic control. As per FAA recommendations for oceanic and international operations, pilots are to report their position to the appropriate air navigation service provider for that region before entering a new flight information region. Pilots should report their position after the first 30 minutes of flight and at required intervals thereafter if the route does not have designated reporting points.

The oceanic airspace presents surveillance limitations that make it hard to pinpoint the exact location of an aircraft in an emergency. Radar keeps track of aircraft position in real time, but coverage begins to lessen more than 150 miles from the coast and in remote airspaces. Since there is not a constant update of an aircraft's location in those areas without radar coverage, pilots are to report their position. Updating one's position can be problematic. If there are disruptions from weather and atmospheric conditions over the ocean, it may take a flight crew 10 to 20 minutes to relay their position using radio. This could pose a serious situation in the event of an emergency when changes in altitude or course are required in proximity to other aircraft. Figure 14-8 illustrates just a small portion of global oceanic traffic through depictions of flight tracks.

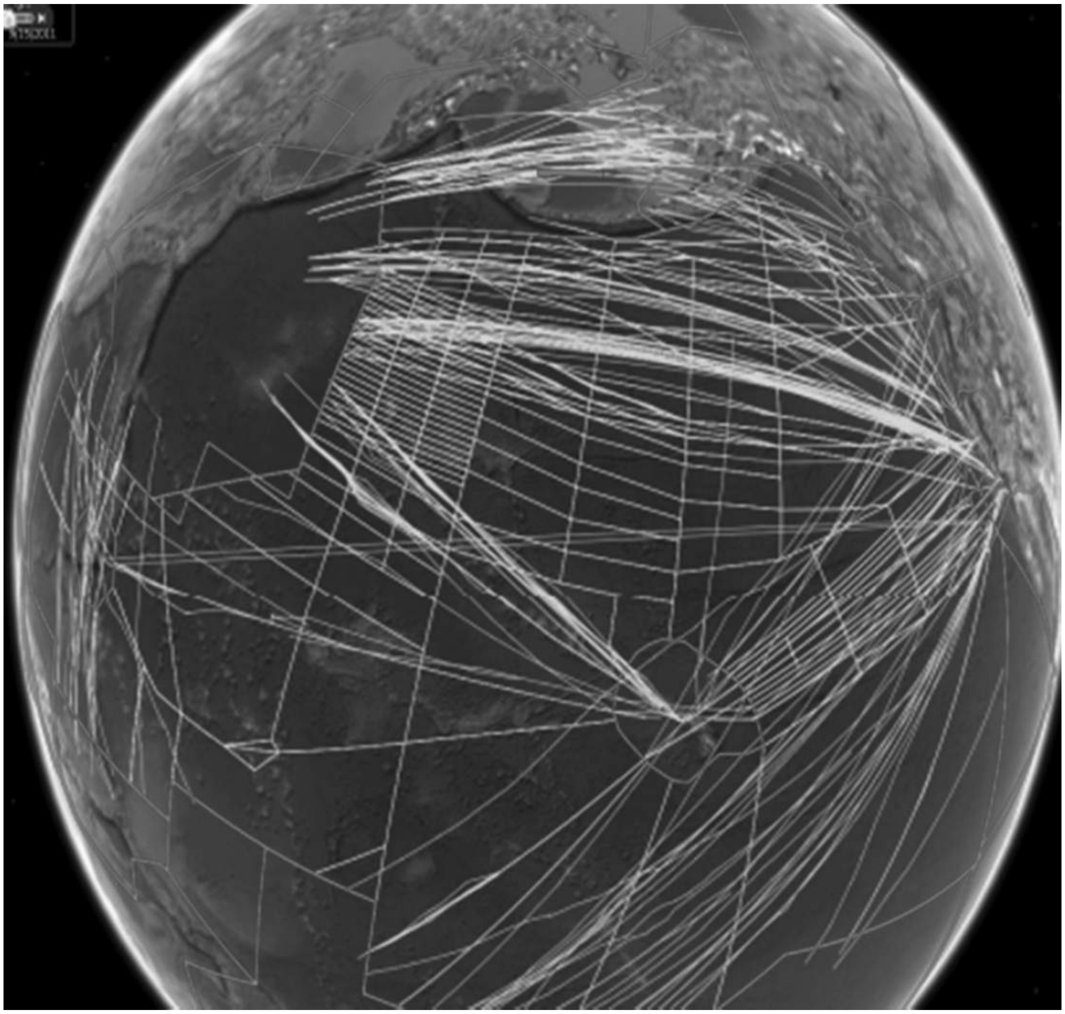

FIGURE 14-8 Despite being over remote places such as oceans, these tracks show that there is still a significant amount of air traffic. (*Source: FAA*)

Another challenge posing a threat to safety in oceanic traffic monitoring is the difficulty of communication and coordination between air traffic control centers. International air traffic control is divided geographically based on flight information regions. This problem was highlighted by the accident of Air France Flight 447. There was a lack of communication between the controllers about the projected passage of the plane from one airspace to another.

The disappearance of Malaysia Airlines Flight 370 in the Indian Ocean is the most recent event that has pulled the international aviation community together to improve aircraft tracking. Professionals would like to see position reporting decreased to 15-minute intervals, with the ability to increase communication in the event of an emergency. Such capabilities should allow the regular and automatic transmission of aircraft position information. Currently, commercial airline operators are responsible for aircraft tracking. The 15-minute frequency is

the best compromise between the desire to know an aircraft's precise location and the cost of transmitting data.

When an aircraft does disappear, investigators search for data that can show them the last position of the aircraft and what happened. The current, crash-resistant flight and data recorders possess such data but must first be located in order to retrieve the data. The future may bring the requirement for aircraft to transmit certain data to ground stations in real time so that investigators can quickly narrow the area of search for wreckage and also hone in on factors that potentially contributed to the event. However, modern aircraft create a large amount of recordable data and technical solutions are required in order to transmit the data in real time to ground stations.

For example, an article in the March 2013 issue of *Computerworld UK* states that Virgin Atlantic expects to receive half a terabyte of data from each Boeing 787 per flight, whereas only 4 years ago, all the commercial airlines combined generated 11 terabytes of data for the entire year. One terabyte equals a trillion bytes of data. The growth in the amount of data available for transmission is increasing at an alarming rate and creating transmission systems that span long distances with the bandwidths to accommodate large amounts of data streaming from tens of thousands of aircraft simultaneously may prove expensive. Transmitting only position data would reduce the bandwidth requirements and would assist in locating the wreckage if an accident has occurred, but it would prove to be of little value to accident investigators.

Another proposal from the community was to change communication standards between air traffic service providers and airlines to improve coordination if there is an emergency. Such changes would create protocols and standards to improve the response to instances of missing position reports or other dangerous situations. Additionally, aviators have suggested that position reports should always include latitude, longitude, altitude, and time information because having this information allows for more precise positions.

Several technologies exist that could help achieve enhanced tracking. One is the *Aircraft Communications Addressing and Reporting System (ACARS)*, which provides digital datalink for transmission of short messages via air band radio or satellite between ground stations and aircraft. It has the capacity for enhanced reporting if the system is triggered by an unanticipated altitude change or a flight level below a specific altitude. A second viable option is the *Future Air Navigation System (FANS)*, an avionics system that provides a direct data link communication between air traffic controllers and pilots. Information includes clearances, pilot requests, and positioning reports. The airline ground system can access pertinent information about the position of the aircraft using special

applications.

Despite having technologies that could enhance the safety of oceanic tracking, there are still some obstacles associated with them. One major concern with ACARS and FANS is that they are not tamper-proof. Consequently, anyone with knowledge about the technologies could disable both systems and the aircraft's transponder. Without these systems, it is not possible for the aircraft to send position data. Another hurdle is cost. To equip a single aircraft with ACARS could cost up to $100,000. Similarly, adding FANS would result in an additional cost of $250,000. These are not small amounts, particularly for operators of large fleets of aircraft where costs rapidly add up to multimillion dollar expenses.

Tracking extends beyond just airplanes in flight. Another issue to discuss is the location of plane wreckage if it does crash into the ocean. The wreckage and flight data recorder are essential items to have for the accident investigation. As a result, the safety community is taking measures to make sure that these items can be located whenever there is an accident. Ocean currents can move aircraft wreckage from its initial point of impact. Aviation professionals are looking at extending battery life on underwater locator beacons that are attached to flight recorders. Also, the industry has discussed including a second beacon that has a greater transmission range.

International Civil Aviation Organization has developed the *Global Aeronautical Distress and Safety System (GADSS)* to work on the above matters. This system addresses the concern of locating an aircraft's position both during and after the accident sequence. GADSS consists of four key components. First, it aims to improve the aircraft tracking system by increasing position reports when abnormalities are detected. Second, GADSS wants to incorporate an autonomous distress tracking system that would act independently from the regular aircraft tracking system. Unusual attitude, speed, acceleration, or failure would trigger an alert. Third, there would be an automatic, deployable flight recorder. The flight recorder would separate automatically from the aircraft in the event of an accident. Fourth, there would be an improvement in procedures and management of information. Other future changes include improved coordination and information sharing and enhanced training of emergency teams.

SURFACE TO AIR MISSILES

Terrorists have long understood the importance of air travel in today's society, and as a result, made it one of their prime targets. In 2001 the terrorist

organization al-Qaeda declared the incapacitation of the U.S. economy as their primary goal.

That same year, the 9-11 terrorist attacks used the airline industry as a tool for wreaking both terror and economic mayhem. Fast forward to today, and another very present threat to commercial aviation safety is surface to air missiles (SAMs). Typically used for war, the missiles are launched from ground vehicles or shoulder-mounted units to destroy aircraft or other missiles. The threat itself is not new. In 1970, an Alitalia DC-8 was hit by a SAM near Damascus, Syria.

There have been more recent incidents in which commercial planes have been targeted, shot at, and even hit by SAMs. In 2002, an Arkia Israel Boeing 757 flying near Mombasa, Kenya, narrowly averted being hit by two SAMs. In 2014, another commercial airliner was hit by a SAM but faired much worse. The aircraft was a Boeing 777 operating as Malaysia Airlines Flight 17 (MH 17). The aircraft was on a scheduled flight from Amsterdam to Kuala Lumpur. While crossing over the Ukraine-Russian border, militants mistakenly shot down the plane, killing all 283 passengers and 15 crewmembers on board. Figures 14-9 through 14-11 depict the tragic sequence of events that downed the jet.

FIGURE 14-9 An image captured from an animation showing the launch of the SAM that shot down MH 17. (*Source: Dutch Safety Board*)

FIGURE 14-10 An image captured from an animation showing how the captain of MH 17 may have seen the SAM instants before it exploded just outside of the flight deck window. (*Source: Dutch Safety Board*)

FIGURE 14-11 An image captured from an animation showing the explosion of the SAM that shot down MH 17. (*Source: Dutch Safety Board*)

Unfortunately, commercial planes are quite vulnerable to SAMs. Such aircraft have takeoff and landing patterns that are predictable, unlike military aircraft that can vary such patterns to make it harder for terrorists to set up a missile launch to intercept their target. Second, some missiles have heat-seeking or radar-guiding capabilities. Furthermore, some combat aircraft have the ability to launch flares that are designed to confuse the SAM's guidance system by sending out waves of heat over a wide area or have chaff or jammers that confuse radar units.

Commercial passenger airplanes have several components that produce significant heat signatures, large radar signatures, and do not possess flare, chaff, or jamming systems, thus making them particularly susceptible to SAMs. However, laser jammers are an emerging technology that could provide substantial protection against missiles. They work by overwhelming the signal produced by the missile and then substitute a special signal transmitted by the laser in an effort to divert the missile. This would allow for the diversion of a single attack. At least one commercial airline already uses jammers to mitigate the SAM threat, although such use is by no means widespread. Other viable defensive options exist but they are not best suited for commercial airline use.

When such technologies are not used, the best way by which commercial flight crews can avoid getting hit by SAMs is to avoid potentially dangerous areas in the first place. The FAA publishes information about no fly zones through Notices to Airmen (NOTAMs), which place restrictions on commercial flights operated by U.S. airlines. The geopolitical situation of a region can greatly influence the FAA's decision to add a region to the forbidden list. There are two levels of warning. A Red Zone typically prohibits flight at any level of altitude, while a Yellow Zone denotes areas that pilots should exercise caution when flying over. Figure 14-12 shows areas of risk from SAMs during overflights on long-duration trips out of London.

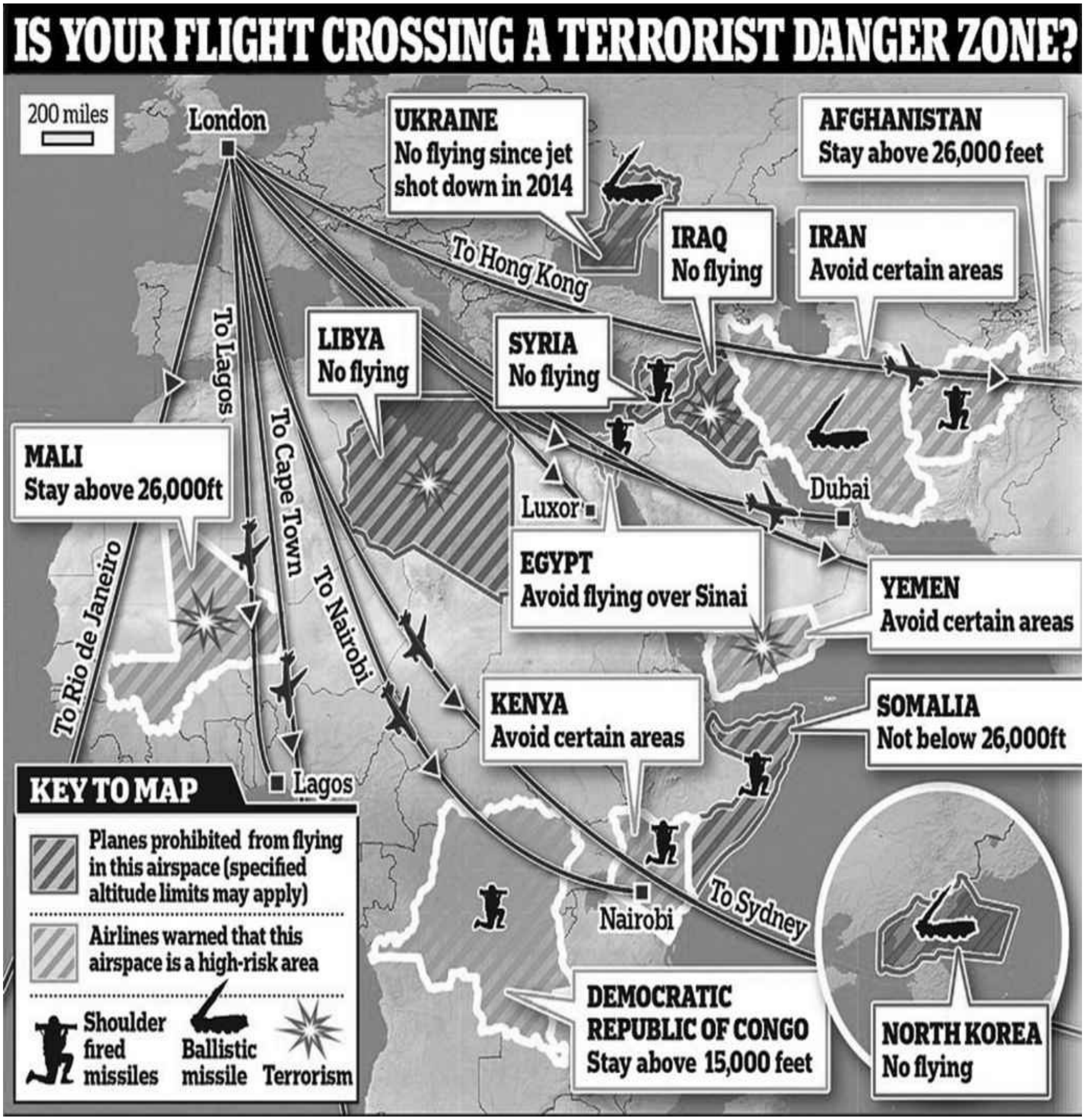

FIGURE 14-12 In 2015, the FAA produced this depiction of current flight profiles out of London that would be vulnerable to a surface to air missile attack. (*Source: FAA*)

In the aftermath of the MH 17 shoot-down, ICAO stated that countries have the responsibility to alert others of any potential risks to civil aviation operations in their airspace. However, some leaders argue that countries could jeopardize national security and intelligence gathering activities if they share that information. Moving forward, governments must work together to create channels to make critical threat information available to international civil aviation authorities.

Countering the proliferation of missiles is a top security priority for the United States, among other reasons, because SAMs pose a serious threat to the commercial aviation industry. Policy changes could potentially combat the threat of SAMs. The United States can fight against missiles becoming widely available in the international weapons marketplace through buyback programs and technology control. Many existing missiles that are in the wrong hands are old and obsolete. While they may be ineffective against modern military aircraft, they can still pose a threat to civilian aircraft.

One recommendation that the U.S. Department of Homeland Security has suggested to prepare pilots for handling missile threats is to increase pilot training, such as putting pilots through specific simulator exercises using missile attack situations. These scenarios would benefit pilots by preparing them to fly and land a damaged aircraft. A missile strike that does not cause a catastrophic structural failure would likely be survivable if the crew is adequately trained to handle such a situation. In fact, this did happen in Iraq to a DHL cargo flight in 2003. Shortly after the Airbus 300's departure, a SAM struck the plane's left wing, causing a fire and loss of the hydraulic control system. The event occurred near Baghdad and the Airbus 300 managed to land, although severely damaged. Despite the damage, the pilots were still able to land the plane safely.

There are measures that can be taken to improve airport security to protect commercial aviation from SAMs. An increase in security, surveillance, and patrols in the areas of airports with commercial aviation will only protect aircraft to an extent. Approach and departure corridors are still within the range of SAMs and stretch for several miles beyond airport property. Security forces would need to determine locations beyond the airport property that have a higher threat potential and where aircraft may be susceptible to attacks. Forces will then be able to patrol areas to counter threats to security.

Currently, there is no single solution to ensure security in the sky from SAMs. Rather, a combination of defensive options is needed to guard against this serious threat.

AIRCRAFT DESIGN

Aircraft Icing Prevention

Aircraft deicing and anti-icing is a critical part of preventing frost, ice, or snow from building up on the wings of the plane. At first glance, it may not seem like this type of precipitation could affect flight, but in fact, it has a critical impact. It has been recognized as a significant safety hazard affecting the aviation industry

today. That is why aviators take many safety measures to ensure that planes get cleaned of contaminants and stay clean when frozen precipitation occurs or conditions may lead to freezing of moisture on an aircraft.

Although the hazard posed by such conditions is not new, the future of commercial aviation safety will likely feature ways to enhance the detection of contaminants and improve a stall detection system's accuracy when airfoils are contaminated. Currently, there are no routinely used systems that automatically detect the presence of icing on lifting surfaces, such as aircraft wings and tails, during flight. Furthermore, current stall warning systems also do not take into account the disrupted airflows that occur during icing and can produce aircraft aerodynamic stalls well in advance of any warning.

The contamination of the aerodynamic surfaces on an aircraft can prevent the generation of sufficient lift to sustain flight, can impede the movement of control surfaces, and can make the aircraft uncontrollable. Often the first time a pilot notices that contamination exists is during takeoff, when the aircraft is unable to lift off, or when the aircraft becomes airborne but is unable to climb out of ground effect. When contamination occurs unevenly, the aircraft may still be able to become airborne, but, as soon as the aircraft exits ground effect, an asymmetrical stall may develop which results in a wing dipping and contacting the runway.

The threat of icing occurring during ground operations is particularly worthy of discussion because aircraft equipped with onboard anti-icing and deicing systems are often severely limited in operating such systems while the aircraft is on the ground.

Future efforts to enhance safety with ground icing must stress to pilots that they should always perform a tactile contamination inspection of airfoils prior to flight. Contamination can be extremely hard to detect, particularly at night or during precipitation when inspections are rushed to get the plane out of the rain, snow, or sleet. Pilots should be taught to remove their glove when performing a tactile contamination inspection of the airfoil since a gloved hand is unable to detect the presence of small amounts of contamination. Such miniscule quantities can cause a significant aerodynamic problem. Yet another challenge is presented by the inaccessibility of airfoils on the empennage, or rear-most section of an aircraft, particularly for T-tail assemblies. Pilots must often rely on instinct, deduction, or trust in another observer to ensure that aircraft horizontal stabilizers are free of contamination when performing external inspections of aircraft before departure.

Most airlines use a glycol–water mixture to remove ice during ground operations. Next, operators apply a separate treatment of a thicker fluid, similar

operations. Next, operators apply a separate treatment of a thicker fluid, similar to a gel, to keep the ice from forming before takeoff. Departure acceleration clears the fluid from the wings by breaking the chemical bonds that hold the fluid together, allowing no disruption to the aerodynamics needed for flight.

An interesting technology scientists are exploring to address icing hazards and which may be developed in the future stems from poisonous frogs. In an article in a 2015 edition of *Advanced Material Interfaces* written by mechanical and aerospace engineering researchers at Arizona State University, this new technology was showcased as a means for aircraft wings to de-ice themselves by secreting antifreeze, similar to the way a dart frog's skin secretes toxin when it is threatened. Two thin layers would be sprayed onto the wing of the plane. The outer, porous layer would protect the inner layer against outside elements while the inner layer would be infused with antifreeze. As the outer layer fails, the inner layer would release the antifreeze to prevent ice accumulation. The researchers tout that such a two-layer skin model can delay accumulation of some freezing precipitation up to 60 times longer than the next best material. This should not affect airflow over the wing, but instead, be a safe option to keep wings clean of ice and frost during flight.

To understand the critical role that deicing plays in aviation, it is important to note that business analysts predict it will be a billion dollar market by 2020. With aviation projected to grow internationally, countries around the world are expected to witness a surge in demand for aircraft deicing systems. More vendors are entering the market with different technology and equipment for containment, collection, recycling/recovery, and treatment.

Infrared systems are another emerging technology that airports are turning to for deicing. Planes can park in an open hangar where infrared radiation melts frost, snow, and ice, and minimum glycol is used. Advantages to this include lower fluid costs, being more environmentally friendly, and faster throughput. However, the technology has been slow to catch on because it is difficult to find the space to build the infrared structure since it is about 100 feet tall, and a structure that tall cannot be built too close to an active runway.

Improved weather forecasting can also help airports with planning for deicing and anti-icing. Continuously updated forecasts help airport operators make decisions on deicing procedures. If more than necessary resources are used for deicing as a result of inaccurate forecasts, it is a waste of manpower and money. The National Center for Atmospheric Research together with the FAA developed the *Weather Support to Deicing Decision Making (WSDDM)* tool. Data comes from Doppler radars, surface weather stations, and snow gauges within the terminal area. The system then graphically depicts this information for

airline station controls, dispatchers, deicing facilities, airline snow desks, and FAA air traffic managers to help make decisions about the appropriate measures to take care of the aircraft.

Simulators have recently emerged that allow deicing personnel to train with icing conditions. The cost of deicing/anti-icing training is expensive and sometimes prevents new employees from getting adequate training before critical times. Simulators mimic video games in that they have controls that are exact replicas of the controls in the deicing equipment. Such simulations also allow employees to change the time of day, control the amount of precipitation, and adjust the weather to create different, challenging, and realistic scenarios.

Although aircraft on the ground are particularly vulnerable to ice accumulation, the future of commercial aviation safety must also address the detection and removal of contamination once aircraft are in the air. To that end, the FAA recently tightened their standards for icing certification. The update requires U.S. manufactures to show that aircraft can operate safely in freezing drizzle, freezing rain, and conditions known as “super-cooled large drops” (SLD). These types of precipitation can severely degrade airplane performance and handling. The intent of the rule change is to ensure future fleets will be able to withstand unexpected encounters with icing conditions with more resiliency. Since 1996, the FAA has issued 112 rules to correct unsafe conditions in aircraft related to icing. Future research also includes the design of icing detection systems, especially for tail icing, which is a significant weak area in the fight against the icing hazard to aircraft.

SOFTWARE SAFETY AND CYBERSECURITY

The attention of aviation safety experts is frequently called to new areas, often in response to accidents attributed to conditions that were previously downplayed. Such hazards are sometimes referred to as “sleeping giants” since they describe conditions that do not receive the attention merited by the severity that they pose and which could one day produce a catastrophic event. In the 1970s and 1980s, such a sleeping giant was Controlled Flight into Terrain (CFIT). In the 1990s, another sleeping giant was wiring safety. Some experts point to a current sleeping giant as being software safety and security. A future area in commercial aviation safety may be expanding awareness of software failure modes and the vulnerabilities of software to intentional attack by terrorists.

Software safety first caught the wide attention of the public following the 1962 self-destruction of NASA’s Mariner 1 spacecraft, bound for Venus, 5 minutes after launch when a coding error sent it off course. The problem was

once more highlighted to the public during the 1999 loss of the NASA Mars Climate Orbiter. The orbiter was a 338 kilogram robotic probe launched by NASA to enter Mars orbit and perform meteorological observations. However, communications were lost during orbital insertion. The NASA Mishap Investigation Board for the Mars Climate Orbiter published a report in November 1999 and concluded that the root cause of the accident was that programmers had used English units instead of metric units when coding a thruster performance software file for “Small Forces” that was used in the trajectory models for the spacecraft. The result was a trajectory that resulted in a 57-kilometer high orbit instead of the planned 226-kilometer orbit. The orbiter was lost at a cost of approximately $650 million.

The Mars Climate Orbiter was just one accident in a long string of losses associated with software bugs that also includes military and commercial aviation. In 2007, computers on board six U.S. Air Force F-22 fighter jets simultaneously failed when the formation flew across the International Date Line, resulting in the loss of pilot communication and navigation systems.

In 2009, a Boeing 737 operating as Turkish Airlines Flight 1951 jet crashed on approach to Amsterdam. The altimeter, one of two on the airplane that displays the height above ground, malfunctioned. In a perfect example of different factors combining to produce an accident, the incorrect altitude reading at the time when the aircraft started to follow the glidepath on approach triggered the software to greatly reduce power to the engines because the aircraft thought landing was imminent. The software simply followed the programming, although any human pilot actually hand flying the aircraft and aware of the actual altitude above landing would not have reduced engine power so significantly in such a circumstance. The crew noticed this too late to take the appropriate action to increase the thrust to recover, causing the aircraft to stall and the plane to crash.

Looking at some numbers about software code will help explain why protecting aircraft against coding errors and hacking can be complicated. The Boeing 787 has 6.5 million lines of software code, a number that has doubled every 4 years since 1970. The same reliance on software is present in modern cars. The 2010 Mercedes S Class has 20 million lines of code. Software now constitutes 70% of an aerospace system’s development cost. When an automated analysis was performed of the 2 million lines of code used in the Martian rover Curiosity to detect anomalies, around 2,000 defects were detected. Some scientists estimate that 15 to 50 errors are present in each 1,000 lines of code.

Software safety also applies to the support structure for commercial aviation.

In 2015, a software glitch in a new and much touted air traffic control computer system forced controllers to revert to backup, manual procedures. The result was almost 500 commercial flight delays and another 470 cancellations up and down the U.S. East Coast. The failure was traced to the Lockheed Martin En Route Automation Modernization (ERAM) system that replaced a 40-year-old En Route Host computer system managing traffic in U.S. airspace at all 20 of the FAA’s en route air traffic control centers.

In aviation, glitches in software extend beyond possible coding errors. The aviation industry has made great strides in physical security since the September 2001 terrorist attacks but it still has not fully addressed potential cyber threats. Possible security breaches could cause severe harm to everyday operations. Commercial aviation operations depend on a highly networked and interconnected system that encompasses voice and data communications between aircraft, air traffic control, and satellite stations feeding data through this system. Herein lies the problem that the more networked the environment, the greater the opportunity to exploit any of its weaknesses.

Cyber threats will continue to persist in the 21st century and may possibly grow, so there will continue to be a need to protect confidentiality, integrity, and the availability of information systems as the number of passengers and flights increase internationally. Incidents recently have demonstrated that terrorists are increasingly interested in targeting the aviation sector. In 2011, radio hackers spoke on the frequency of British air traffic controllers, giving fictitious instructions to pilots and making fake distress calls. Again in 2011, the Internet security company Pure Hacking executed an infiltration on an airline network. In just one attack, the tester was able to completely compromise an airline network, which included capturing credit card numbers, plans, communications, and databases.

Groups interested in hacking include three main parties, all with different objectives:

- Hackers, who represent the largest group, are most interested in the challenge of executing a security breach rather than trying to disrupt operations.
- Terrorists are arguably the most serious threat. Aviation continues to be a prime target for those seeking a visible, damaging impact on public infrastructure. Though terrorists mainly used the Internet to communicate for recruitment and propaganda, there has already been some evidence of them conducing cyberattacks.
- Nation states are the third group interested in cyberattacks. Their hostile

activities have targeted the aviation industry to gather sensitive and proprietary information rather than targeting airports, communication, or aircraft in flight.

Aviation professionals in the United States and Europe disagree on the best way to protect the industry from potential cyberattacks. The *European Aviation Safety Agency (EASA)* believes that all airplanes, regardless of size, should be subject to the same cybersecurity standards. On the other hand, the FAA believes that only larger planes should be subject to stricter requirements. There are no strict regulations mandating the industry to report cybersecurity threats and incidents. Some lawmakers are urging that there should be more mandated reporting of breaches in airlines since they are such a critical component of a country's economy.

The EASA recently established a special committee to fight the continuously changing landscape of cyber threats against aviation. The threat seems daunting and immediate, although it should be noted that, to date, no verified cyberattack has successfully hacked a commercial airliner's system while in flight. Yet, this does not mean that hackers would not target an aircraft's networks, ground-based systems, navigation, and cabin entertainment. The field of software safety and security will likely receive significantly more attention in the near future to protect commercial aviation safety.

HUMAN PERFORMANCE AND RELIABILITY

LASERS

One hazard to pilots during flight that bears mentioning is how lasers have recently become an increased threat. Over the past few years, there have been more and more reports of people on the ground shining lasers up at aircraft. It may not seem very harmful, but it actually is equivalent to the flash of a camera in a pitch black car at night. Although permanent damage to the eyes from laser exposure in these circumstances is rare and such laser effects on vision are usually resolved in 2 to 3 days, there are precedents for pilots being visually disabled for several years due to laser strikes. The light can temporarily blind crew, create glare, and cause distraction. A laser hitting the glass windows on a flight deck may refract light across the windshields, making it very hard to see outside. Imagine pilots being temporarily blinded when rolling down the runway for takeoff or in the final seconds of an approach prior to landing. The effects could be disastrous.

Furthermore, some lasers operate in the infrared part of the light spectrum and can damage pilot vision while being invisible. In other words, pilots may suffer laser strikes and not know that they have been hit. As of 2015, the FAA recorded over 5,000 laser strikes to aircraft per year, up from 2,837 for 2010. Some of the leading airports reporting laser strikes in the United States are Los Angeles, Phoenix, Houston, Las Vegas, and Dallas Fort Worth. Since the effects of the laser severely compromise the safety of pilots, in 2011, the FAA started imposing civil penalties on people who pointed lasers at aircraft. In that year, the maximum fine was $11,000. However, since the hazard to aviation safety posed by lasers is so serious, Congress increased the penalties in 2012, and the FBI has made it a felony to disrupt airplanes with lasers. Anyone convicted of pointing a laser at an aircraft can now be sentenced to 20 years in prison and a $250,000 fine. Recently a man was sentenced to 14 years in prison for targeting a Fresno Police helicopter with a laser. In addition to pursuing the users of lasers, lawmakers have also attempted to legislate the sale of high-powered, long-range lasers, which can produce devastating effects yet are rather inexpensive and easy to purchase.

PSYCHOLOGICAL FITNESS FOR DUTY

On March 24, 2015, an Airbus 320 operating as Germanwings Flight 9525 flying from Barcelona, Spain to Düsseldorf, Germany crashed in the French Alps, killing all 150 passengers and crew. As details started to emerge in the days following the horrific crash, it became known that pilot Andreas Lubitz had deliberately crashed the aircraft.

The initial suspicions were confirmed in the preliminary report published by the French authority responsible for civil aviation accident investigations, the *Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile (BEA)*. The initial findings indicated that the first officer locked the captain out of the flight deck and set the aircraft on a collision course into the terrain. Although pilot suicides while flying had occurred in the past, the Germanwings disaster caused world shock at the notion that one mentally unstable person could bring so much pain and suffering to others in such a violent fashion.

Equally shocking was learning how limited most aircraft operators are to detecting the mental health problems of employees. The Germanwings pilot had been treated for depression for a lengthy period prior to obtaining his pilot credentials and had known suicidal tendencies. Nevertheless, he was still certified to fly an extremely sophisticated piece of equipment and had the lives of passengers in his hands. A study of the tragedy and of other similar events in

aviation has revealed interesting findings. Figure 14-13 shows investigators examining the wreckage of Germanwings Flight 9525.

FIGURE 14-13 Investigators look over the wreckage of an airliner deliberately crashed by a suicidal pilot. (*Source: French Ministry of the Interior*)

The Germanwings tragedy brought the issue of mental health to the forefront in 2015, but there is a significant list of previous events that showcase the ongoing importance of *psychological fitness for duty*. In 1976, a pilot stole an Aeroflot An-2 and flew it into the neighborhood where his ex-wife lived, killing 11 people on the ground. In 1994, a disgruntled Federal Express flight engineer facing termination of employment and flying as a deadheading passenger attempted to hijack a Federal Express McDonnell Douglas DC-10 operating as Flight 705. The hijacker wanted to kill the crew with hammers so that their injuries would look like an accident and then planned to crash the aircraft so his family could benefit from his life insurance policy.

Other events pointing to mental instability have taken place in Japan, Morocco, Indonesia, Botswana, and off the coast of New York, and some have been prevented that otherwise would have been disastrous. For example, in 2012 a JetBlue captain turned to his first officer before departing on a flight and stated that they would not be flying to their destination, and instead, started yelling about religion and terrorists.

about religion and terrorists.

In March 2016, *The Times* revealed that 2 months before the Germanwings Flight 9525 disaster, an eerily similar event almost occurred. In January 2015, an Italian pilot flying a commercial airliner from Rome to Japan, apparently distraught at the notion that his wife was threatening to leave him, texted her saying that he would kill himself along with his 200 passengers. The wife alerted officials who quickly stepped in and remove the pilot from duty prior to the flight, without the passengers knowing anything unusual had occurred. The pilot is reportedly still on suspension and under psychological evaluation.

One of the challenges at the heart of these fitness-for-duty events is that there is no consistency across the world for dealing with pilot health certification. In fact, most airlines do not have any process for the periodic assessment of employee mental health once they are hired, even though conditions such as depression, anxiety, and mania can be diagnosed. In 2013, the National Survey on Drug Use and Health (NSDUH) estimated that approximately one in five Americans meets the diagnosis for mental disorders. In the United States, medical confidentiality is controlled in great part by the *Health Insurance Portability and Accountability Act (HIPAA)*, which prohibits doctors from disclosing a patient’s health information without written consent. However, a doctor still has an ethical obligation to disclose information when concerned that the patient may pose a serious and imminent threat or harm to the public.

Airline pilots are required to undergo periodical medical screening, but such tests are not designed to detect psychological problems. Instead, the tests tend to rely on the self-reporting of conditions by the individual. The FAA can fine pilots up to $250,000 for omitting or providing false information concealing health issues that could impact fitness to perform duties. There are no clear and quick methods for doctors or regulators to intervene if they suspect mental problems. It is mostly up to individuals to self-police and report problems. Individuals may be reluctant to report psychological problems due to the stigma that they may have about mental illness or out of fear that it may lead to negative action against their professional certificates or employment. Coworkers may not report suspected problems in others because they do not want to be branded as someone who reports colleagues.

To encourage pilots to report self-detected mental illnesses, in 2010 the FAA started allowing the issuance of medical certificates even if a pilot takes certain medications for mild to moderate depression. Before such a provision, the disclosure of the conditions would quickly ground the pilot, and therefore, many pilots hesitated to discuss their concerns about mental health with physicians As a result, pilots were avoiding the treatment they so critically needed. The new

provision only applies to very specific medications and requires that the pilot also abide by certain clinical conditions.

Research is required to determine how much psychological benefit is gained from physical conditioning and other techniques, such as meditation and mindfulness training. All aviation professionals should be aware that psychological problems, of varying intensity, are not uncommon and that they should be observant of coworkers.

Four months after the crash of Germanwings Flight 9525, in response to the preliminary investigative report and due to the lack of current standardized guidance across the world, the EASA produced several recommendations for consideration by the European Commission:

- Requiring at least two people on the flight deck at all times
- Random drug and alcohol testing programs
- The system of oversight for medical examiners
- Creating a European aeromedical data repository

The following month, the *International Federation of Air Line Pilots' Associations (IFALPA)*, representing the interests and rights of pilots, responded to the EASA recommendations by countering as follows:

- Systematic psychological or psychiatric evaluation should only be performed when a pilot is being tested as part of the hiring process and prior to employment.
- Once employed, if a need arises for additional testing, known as *for-cause* testing, then such testing should ensure that safeguards are in place to protect the pilot.

The balance between trying to prevent a recurrence of a tragedy such as Germanwings Flight 9525 and protecting individual privacy rights presents a formidable challenge going forward. The debate centers on the question of whether privacy laws protecting medical records from release should provide some flexibility for employers of employees with special responsibilities, such as airline pilots, aviation maintenance technicians, and air traffic controllers. Employers need the flexibility to manage these sensitive issues, yet labor groups often feel that such flexibility could compromise privacy, and therefore, prospects of continued employment.

Although a more robust system for detecting emerging mental health

problems and reporting the condition so that pilots receive prompt medical attention may prevent future versions of Germanwings Flight 9525, pilot health advocates have also voiced the concern that revealing mental health conditions in the interest of safety may actually work against safety. They argue that the provision may cause some pilots to attempt to hide their condition instead of seeking treatment, although the counter-argument is sometimes made that pilots already frequently hide medical conditions that may negatively impact their performance.

One solution as we move into the future is for each airline or flight department to implement a carefully constructed *fitness for duty* program as part of their Safety Management Systems (SMS). It is important for the program to have confidentiality, dignity, and respect as cornerstones to promote participation. When pilots start initial or recurrent training in the airlines, they enter intense training and are closely monitored. It is easy to detect any impaired aviators during this time because of their high contact with trainers. Back in the cockpit though, red flags for poor mental health may go unnoticed.

The topic of impaired aviators is gaining attention, but this can neglect the other key members of a safety value chain, including flight attendants, air traffic controllers, ramp agents, and dispatchers. Since there is not a link that bridges awareness across all aviation professionals, the NTSB’s 2015 Most Wanted List for safety improvements includes items that address these issues. Among the 10 items cited, the NTSB urgently recommended improving requirements for medical fitness for duty and eliminating substance impairment in transportation.

An important alliance between the European Society of Aerospace Medicine (ESAM), the European Association for Aviation Psychology, and the European Cockpit Association has formed to endorse a key set of guidelines for assessing pilot health and raising awareness for mental health issues. The initiative puts recognition and acceptance of potential mental health issues as the first step in solving them. There should be a positive environment created for pilots to suggest issues and their requests for assistance to be taken seriously. Pilots should be able to share their concerns confidentially without it affecting their fitness to fly.

India is also taking measures to improve the process for evaluating the mental health of their pilots. Psychometric tests for pilots of Indian airlines were set to begin in the first half of 2016. The country’s Institute of Aerospace Medicine had started contemplating these tests after the Germanwings crash and set up a panel of experts to decide on the psychometric tests for pilots. This panel recommended four levels of tests. First round testing would start at the time a student wants to enroll for a flying school. The other three stages would be at the

time of joining an airline or charter company, when being promoted to captain, and whenever they exhibit any abnormal behavior.

Life can be difficult, with some aviation professionals suffering from post-traumatic stress syndrome or stressful family events that are difficult to compartmentalize when performing professional duties. There are many psychiatric disorders that are not screened for that could greatly affect the performance of aviation professionals. Future debate will continue on which direction the aviation community should go for when screening for these types of problems.

SAFETY MANAGEMENT SYSTEMS

SMS VARIABLE INTERDEPENDENCIES

Commercial aviation has managed safety in one way or another since the dawn of flight, but over the last decade, regulating government agencies has created a useful business approach to accident prevention described as Safety Management Systems (SMS). The primary goal of SMS is to institutionalize the processes for safety decision making throughout an organization that relies on managing safety through measurement. It is a scientific approach to managing safety.

Whether awareness comes through collected numerical data or the input of employees, recognizing that there are many opportunities to prevent an accident is the first step in moving from a reactive to a proactive or predictive safety culture. Safety is not one-directional: it starts both at the bottom of the organization and top of the organization. Senior management sets the tone for safety and managers are ultimately accountable for safety. CEOs play a critical role and so do all aviation professionals, regardless of their positions.

International Civil Aviation Organization has recommended that all aviation authorities design and integrate a SMS system into their operations. The FAA has begun working on this through setting up the SMS Advisory and Rulemaking Committee (SMS ARC). In addition, they also require that all FAA services and offices adopt a common aviation safety management system (AVSSMS).

By using SMS, organizations are able to examine and make decisions about their operations. From their analysis, they can readily adapt to change, using quantitative methods to promote efficient management through measurement of key performance indicators. SMS strongly supports the continuous improvement of safety through data collection and analysis that provides valuable employee

of safety through data collection and analysis that provides valuable employee feedback. By doing this, SMS has the ability to greatly enhance the safety culture across the organization.

As covered previously in Chapter 12 of this book, the structure of SMS includes four components, with each component broken down further into elements and processes. To reiterate, the four components and their scope include the following:

- *1.0 Safety Policy*: establishing senior management's commitment to improve safety and define the methods, processes, and organizational structure needed to meet safety goals
- *2.0 Safety Risk Management*: determining the need for and adequacy of new and revised risk controls based on the assessment of acceptable risks
- *3.0 Safety Assurance*: evaluating the continued effectiveness of implemented risk control strategies and supporting the identification of new hazards
- *4.0 Safety Promotion*: training and communicating other actions to create a positive safety culture within all levels of the workforce

Even though it is not readily apparent, all of the components, elements, and processes of SMS are interconnected. One key area for the future development of SMS is determining how changes to one component impact the other components and also how one single input can affect the overall SMS. A safety professional attempting to use SMS to prevent accidents will assess the health of the SMS by relying on audit scores and actual operational safety data.

Gains have been made in quantifying the health of each SMS component, but work remains in determining how an alteration of one component impacts the overall SMS and each of the other component within the SMS. Here are some examples: Are changes to safety policy or to key safety personnel more beneficial to the overall SMS? How does an alteration of safety policy impact how change is managed in an organization? How does a change in safety communication impact the effectiveness of hazard awareness? Knowing the specific impact of changing individual SMS components would help to clarify the best steps that should be taken by those charged with overseeing an SMS. It is hard to pick which component should be given priority when all measures contribute to enhancing the overall safety. The future of SMS will include determining such interdependencies and customizing an automated dashboard for each organization that can more carefully control the overall system.

Future SMS development will also focus on quantifying acceptable levels of risk and creating management dashboards for determining when operations are

encroaching on pre-established safety margins. Modern commercial aircraft have become so complex that managing the design, tests, and operations can prove to be a huge challenge. Since the systems are now so complex, new management methods must be developed that are equally capable.

Fusing Proactive Data Streams

One future area in SMS that will see significant development is how to integrate the different sources of non-accident data, sometimes called *near-miss* data, to detect negative safety trends before they cause problems. However, prior to addressing such future data fusion efforts that will allow us to achieve proactive and predictive safety, we should understand how we have arrived at the safety management approach of today.

For a long time, the aviation community's modus operandi reflected a reactive safety approach. The relatively low accident rate of today is greatly the result of investigators who have studied accidents to determine previously unknown or underpublicized hazards, and who then proffered recommendations to prevent future accidents. Studying accidents to determine previously unknown or, sadly, previously known hazards is an example of *reactive* safety. The word "reactive" may have a negative connotation among some, but it just alludes to the fact that accident investigation reveals hazards *after* they cause damage or injury. Reactive safety continues being vitally important to accident prevention.

As safety management in commercial aviation became more sophisticated, safety professionals started channeling their efforts into establishing a proactive approach to safety. Although many commercial aviation operators have embraced the philosophy and tools of proactive safety, others in the global aviation industry lag behind. The lag is particularly true with regard to key players in the safety value chain outside of the flight deck, such as maintenance and overhaul facilities, air traffic control, and airfield operations. Most safety advocates have realized that reactive and active safety alone are insufficient to detect hazards to flights fully. Let us explore the concept of *proactive safety* a little more in depth, since many global aviation operators are still evolving their SMS from *reactive* and *active* safety programs into a *proactive* and *predictive* direction.

About half a century ago, forward thinking safety professionals at a couple of European airlines pioneered the era of proactive safety. They realized that we do not have to wait for bad things to happen to detect hidden hazards. By routinely downloading black box flight data, a process known in the United States as *Flight Operations Quality Assurance (FOQA)*, they recognized that it is possible

to add a proactive element to the active and reactive dimensions of flight safety. Proactive safety is particularly insightful when flight data analyses are accompanied by voluntary reporting programs that foster a nuanced understanding of hazards and the sharing of information that would otherwise only be known to a small group of employees.

Currently, there are several programs that will help aviation professionals achieve a proactive approach to safety management. The FOQA type programs previously discussed are an excellent example of proactive safety since they help explain, in great scientific detail, what occurred during any given flight or across a series of flights. Having those insights proves fundamental to knowing how close we are coming to the limits of safe operation.

A second measure is voluntary reporting, such as through the Aviation Safety Action Program (ASAP) or the Aviation Safety Reporting System (ASRS). This second program is NASA’s voluntary and confidential reporting system for pilots and other aviation professionals for sharing close calls in the interest of improving air safety. ASAP and ASRS help address the reasons why we are approaching the limits of safe operations so that measures can be taken before accidents occur.

Other proactive approaches include programs that observe people in their work settings, such as *Line Operations Safety Audits (LOSA)*, and surveys designed to assess what employees think of their safety culture. Such data sources allow safety professionals to assess the root issues behind why we come close to the safe limits of operations.

Despite numerous avenues for people to address safety in a proactive way, one of the major challenges to the above systems is that there are no robust frameworks to synthesize all the data. All of the systems work independently of each other, making it hard to combine information for a holistic view of aviation problems. The future will see such efforts taken to the next step, the fusing of the data streams so problems are detected even earlier in order to maximize safety. Future SMS development will attempt to find more streamlined and efficient ways to fuse data collected from such proactive programs for creating a clearer picture of what is going on safety-wise in an organization.

Looking even further into the future of SMS, proactive safety will need to be coupled with anticipatory safety and even predictive safety to ensure safe ground operations and flights. Anticipatory safety relies less on probabilistic measurement and can be more qualitative. *Predictive safety* is the investigation of potential hazards that do not yet exist but that might cause damage the very first time they make an appearance. It relies on probability and severity as key

input variables. Some air safety investigators believe that predictive safety is a key missing dimension of many SMS safety risk management and safety assurance programs. They claim that any successful effort to further lower our accident rate must attempt to attack hazards before they present themselves, in addition to relying on the active, reactive, and proactive dimensions of safety.

An example of predictive safety is addressing potential hazards that may emerge when an airline starts operating a new type of aircraft. If the airline is used to operating small aircraft and decides to purchase a larger aircraft, predictive safety may uncover that current snow removal practices at the airport where the aircraft will be based will not provide sufficient wingtip clearance from snow banks on certain taxiways now that longer wingspans are involved. Such a predictive determination allows the operator to work with the airfield manager to adjust snow clearing procedures prior to the delivery of the new aircraft.

TRAINING NEW ACCIDENT INVESTIGATORS

When a catastrophic plane crash happens, it commands the attention of all media outlets. News stations will display countless videos and pictures, and stories will continue to pop up in the newspaper. With all that attention, it is easy to lose sight of the fact that commercial aviation aircraft accident rates are actually at a historic low. The fatal accident rate has been steadily declining over the past decades, and in 2015, the Department of Transportation announced its goal to reduce U.S. commercial aviation fatalities to no more than 6.9 deaths per 100 million people on board. Figure 14-14 shows one of the most recent severe commercial aviation accidents in the United States.

FIGURE 14-14 Picture from the wreckage of the fatal Asiana Airlines Flight 214 in San Francisco in 2013. One of the causes of this accident was automation and a lack of situational awareness. (*Source: NTSB*)

However, one would not think that lowering the accident rate would, in fact, be problematic. With statistics at a 20 year low, the emerging challenge is training new accident investigators for commercial aviation accidents in the Western world because there are less opportunities to investigate actual accidents. Although there are multiple courses to teach eager investigators procedures and policies, they are not getting the hands-on experience needed to develop skills critical to the trade. Accident investigators count on several major skills to perform their duties:

- *Interpersonal skills*: communicating and interacting with people. Accident investigators must work with a variety of people, from witnesses to scientists.
- *Report writing*: each accident requires a report that explains the causes of the crash and recommendations to mitigate the causes and effects. For commercial aviation accidents in the United States, the NTSB investigates and writes the reports.
- *Forensics*: the collection, preservation, and analysis of material from the accident to help draw conclusions about what happened. A few new technologies to aid in this process are electronic mishap tools, optical measurements, and software packages for root cause analysis.

- *Data collection and analysis*: the gathering of information on certain items from the accident or incident to answer questions about what happened. For example, an investigator may collect data on engine performance to see if it was one of the factors of the crash.
- *International cooperation*: working with authorities from around the world to gather information and possible wreckage. For the MH 370 flight that went missing, a few of the parties involved include Australian, Malaysian, Chinese, and American governments.

Classroom settings are a good environment to learn about these skills, but it is not until investigators get to the field that they truly develop them. Universities can use crash labs, such as depicted in Figure 14-15, or can provide a simulation of hands-on experience by creating virtual crash labs. Much like a video game, these simulations allow students to walk through a wreckage site and examine the scene while dealing with biohazards and working in teams to determine causes. They can even collect data on items such as survival factors, human factors, aircraft structures, operations, and maintenance. The future of commercial aviation safety may become increasingly reliant on virtual reality and other simulations as a way of providing quality training with less actual accidents to investigate.

FIGURE 14-15 A university class uses a crash lab to learn about accident investigation techniques. (*Source: ERAU*)

ENHANCING THE DEPTH OF ACADEMIC EDUCATION

A new addition to the academic world that will help shape the future of commercial aviation safety is the new doctoral degrees in aviation. Until recently, there has been a severe lack of doctoral programs that specialize in aviation, and thus, academic research in aviation safety has been limited to industry, government, and less in-depth academic programs. With the requirement of writing a dissertation, there is tremendous potential for aviation professionals or traditional university students to explore topics in depth that could enhance commercial aviation safety. Now scholars can take advantage of the new research potential previously not present. Three prominent aviation doctoral programs are presented by Embry-Riddle Aeronautical University (ERAU) and the Florida Institute of Technology (FIT) in the United States and Cranfield University in the United Kingdom.

The Daytona Beach Campus of ERAU in Florida is known best for its aerospace engineering and aeronautical science programs, but in 2010, the campus started offering a Ph.D. in Aviation. The focus of the program is to develop aviation scholars who can expand on the existing body knowledge and share their findings with the rest of the community. Students start with coursework in central theories and concepts in the aviation field; then pose and solve theory-based and research-based problems related to real-life scenarios; and lastly develop the leadership, collaboration, and communication necessary for academic work in aviation.

South of ERAU in Melbourne, Florida is FIT. It initially opened to be a training ground for space industry professionals working at what now is the Kennedy Space Center. Today, FIT includes a wide variety of aeronautics, engineering, and science disciplines in addition to aviation studies. Their Ph.D. in Aviation Sciences and Professional Doctorate in Aviation (Av.D) programs offer a customizable mix of theory and practice, which allows students to explore aviation research and apply their findings to today’s industry problems.

Jumping across the Atlantic Ocean, another prestigious Ph.D. program is at Cranfield University. Just 50 miles north of London, it is situated on what used to be a base for the Royal Air Force. Today, Cranfield academics center around science, engineering, technology, and management, offering a Ph.D. in Aerospace among other programs.

These three featured universities join other current and emerging doctoral research programs across the globe to help expand aviation knowledge to include tackling some of the more vexing challenges to commercial aviation safety. The future will hopefully see significant advances to safety based on the

research products from such programs, and the industry would be wise to watch for research findings with great attention so that research recommendations can be implemented into all aspects of commercial aviation safety.

Sample dissertation research topics that have been completed or are currently underway at such institutions, and which could significantly enhance commercial aviation safety, include the following:

- The Precursors of Runway Incursions Classified as Pilot Deviations: Factors Related to Hazardous Events
- The Effects of Ethical Leadership and Organizational Safety Culture on Safety Outcomes
- Cognitive and Behavioral Factors Relating to Aviation Professionalism
- National Culture: Understanding the Impact of Cross-culture on Airline Pilots' Safety Performance in the Middle-East and North Africa (MENA) Region
- Safety Culture Among Worldwide Aircraft and Engine *MRO* (Maintenance, Repair & Overhaul) Providers
- Behavioral Traps in Flight Crew-Related 14 CFR Part 121 Airline Accidents
- Validation of New Technology using Legacy Metrics: Examination of Surf-IA Alerting for Runway Incursion Incidents
- An Analysis of Airport Surface Deviations using the Human Factors Analysis and Classification System (HFACS)

ARTIFICIAL INTELLIGENCE

One area that may have the most profound impact on overall safety in commercial aviation and in other transportation modes is the use of machine intelligence to detect accidents as they are about to happen and alert operators of impending doom. Such an arrangement would effectively constitute the ultimate expression safety information sharing and real-time analysis.

The book has shown how numerous innovations in both technology and human performance have dramatically improved the accident rate in commercial aviation over the past century but it has also shown that the rate of improvement is decreasing given that we have plucked all of the low hanging fruit, so to speak. What will produce the next breakthrough? Are accidents something we can cure, such as a disease? Scientific progress has allowed the eradication of

diseases such as yellow fever, smallpox, and the measles. Some medical researchers believe that cancer may be next on the list. Can accidents be eradicated in commercial aviation, or at least decreased to near zero? Some would argue that much of the developed world already expects a zero accident rate in commercial aviation, but as a global industry, we are not there yet, and in some specific areas, significant work remains to achieve rates comparable to those found in developed countries.

RECENT ADVANCES

Recent advances in machine intelligence are enabling the creation of software that has extremely fast processes. Artificial intelligence can be explained as software with the ability to perceive, understand language, learn, reason, and solve problems similar or greater than a human being. When such software is coupled with other similar programs and tasked with focusing on grasping knowledge and relationships, deep learning networks can be created. What was once the science fiction concept of artificial intelligence is increasingly mainstream for society today. We now have powerful search engines that often times appear downright clever, voice and face recognition programs, driverless cars, and machines that can beat the best humanity can offer in strategy games such as chess, highly complex games such as Go, and game shows such as Jeopardy.

Scientists and engineers involved in developing artificial intelligence are quick to point out that 2015 was a key year since that is when advances in computational power and techniques allowed machine learning to leap out of laboratories and into mainstream use. Significant gains also occurred in machine emotional understanding and the ability to learn deeply and quickly in order to perfect their own processes.

For the past quarter century, leaders of the accident investigation community have promoted the concept that any given accident is the result of multiple causes. Such causal factors can be identified as the accident sequence develops, but only if one knows what to look for as the sequence develops. An experienced air safety investigator can read an accident narrative and quickly start picking out key factors that likely will result in the accident featured in the report. An artificially intelligent safety program could be tasked with learning such causal factors by reading all the accident and incident reports ever written; by observing flight simulator crews as they encounter malfunctions; and by monitoring the minor incidents, major incidents, and near accidents that occur in the millions of commercial airline flights every year. Such learning could be further augmented

by analyzing the hundreds of millions of flight data files collected through FOQA, ASAP, and LOSA worldwide.

Doing so would allow the machine to learn how pathogens combine with operational variables to produce undesirable events of different severity and also to “make sense” of how such combinations can result in nonevents. In other words, the machine would learn greatly from both accident and near-miss information. The process sounds onerous, and it surely would be for any human, but it could actually occur with great speed with modern machine learning systems.

The resulting super intelligence could then be tasked with applying the learning to detection, could have an unrivaled ability to recognize when factors are combining that appear conducive to an unsafe situation, and could provide an alert to the operator when a certain accident probability is reached. Such an *accident probability alerting threshold* could conceivably be set to different levels in order to prevent unnecessary false alerts. For example, a threshold set at 90% would delay alerting until being almost certain that an accident was inevitable, barring any immediate intervention. In comparison, a threshold set at 70% would provide an earlier notice of unfavorable combinations of factors and would catch more developing accident sequences but would also provide more false alarms, meaning that it would have decreased alerting accuracy.

It must be stressed that such an alerting system, if designed, would not take the form of a robot sitting in a jump seat on the flight deck. Science fiction often depicts artificial intelligence as being housed in a robot that mimics human form. Instead, the intelligence could reside invisibly within flight deck systems, monitoring as many variables as possible through a combination of sensors, and comparing the factors detected to the combinations of factors previously learned that resulted in an accident or incident. The concept is best described as an intelligent “agent,” meaning that it is an autonomous entity that monitors with sensors and acts within a given environment to achieve preset goals.

The intelligent agent would rely on numerous types of sensors to obtain data for analysis. Such inputs could consist of laser eye trackers that measure, with great precision, pilot gaze and therefore can infer what is capturing a pilot’s attention at any time, such as a weather forecast or takeoff performance data. Another sensor input could be voice recognition in order to establish precisely what checklist is currently being followed and if any procedures or individual checklists steps have been missed or incorrectly applied. A voice recognition sensor could monitor the intentions discussed during crew briefings, conversations with flight attendants that take place both in person and via interphone, air traffic control instructions that are received, and what information

has been exchanged between different aircraft flight crews and between crews and dispatchers.

The ultimate expression of an artificially intelligent system designed to promote safety would be the networking of independent agents together to create shared learning and also shared recognition of developing situations. If each individual intelligent agent was tasked with continuous learning, real-time analysis, near-casting of events, and alerting, and then shared that information with other agents in the system, the resulting aviation operation would come close to achieving a cybernetic expression of a “guardian angel” with the ability to intervene just before an accident occurs. Prediction of events further in the future would also be possible, with an associated decrease in accuracy the further out into the future that events are predicted. The concept is similar to now-casting in meteorology, where the accuracy of predicted weather phenomena can be quite high in the moments after the prediction is issued and for the period immediately following the now-cast, but understandably decreases in accuracy the longer the prediction is in effect.

SITUATIONAL SCENARIO

What follows is an example of how a network of *artificially intelligent agents* could prevent an accident from loss of control inflight of an aircraft. Imagine an airport where arrivals and departures are operating on parallel runways, as is common, and in which the following situation develops under the monitoring of several intelligent agents networked together to prevent accidents. In the scenario, let us say that Agent 1 is tasked with monitoring weather phenomena at an airport and could detect an atmospheric development conducive to the creation of wind shear that could potentially affect aircraft operating in the airport terminal area. Agent 2 may be aboard an Airbus 380 flying a final approach to the airport and may have the task of monitoring the performance of both pilots. That agent may detect how one pilot is focusing attention on re-reading the missed approach instructions on the instrument approach plate corresponding to the approach currently being flown and may deduct that the pilot is thinking about the possibility of aborting the landing. Agent 3 may be aboard the same Airbus 380 aircraft. It may be assigned the task of monitoring the performance of the aircraft itself as it approaches the runway and may sense a thrust increase along with the associated increase in airspeed which when compared to the fluctuating airspeed due to atmospheric turbulence may be interpreted as a common pilot precaution against the wind shear. That same agent may also model the wake turbulence being produced by the aircraft and

would know the severity of the wake turbulence at any given time, being able to predict how the winds aloft would carry the turbulence. Agent 4 may be aboard an Embraer ERJ-140 that is lining up for takeoff on a parallel runway at the same airport and be tasked with monitoring the aircraft performance. Such an agent would know how much wake turbulence the ERJ-140 can tolerate at any given aircraft energy state and would also be aware of the programmed departure runway. The final key agent in our network for the scenario, Agent 5, may be aboard the ERJ-140 and could be tasked with using voice recognition to detect the controller takeoff instructions and subsequent pilot acknowledgment.

A network of the five previously described artificially intelligent agents may produce a safety alert in the described scenario, recommending that the takeoff clearance to the ERJ-140 be cancelled. The alert could be produced the instant that the network recognizes that a takeoff clearance has been issued to the ERJ-140 crew, who could be warned by the system via a voice prompt such as "Safety alert! Cancel takeoff clearance." The flight crew of the ERJ and the tower controller may be completely surprised and perplexed by such an alert, since there is no obvious safety threat to the departing aircraft. That is because the combination of factors that lead to accidents are sometimes only obvious after an accident has occurred. In the scenario provided, the artificial intelligence network had monitored a large number of factors and had recognized that some of the factors were combining in such a fashion that an accident was highly probable. Therefore it issued a warning. But how did the network produce such a warning? How did it conclude that an accident was probable?

In the example, Agent 1 told the network that the aircraft on final to the arrival runway would probably encounter significant wind shear in the next minute of time. Agent 2 shared with the network that the Airbus 380 pilots were actively aware of the possible need for a go-around maneuver and would probably follow the published missed approach instructions if such a procedure were performed. Agent 3 shared that if such a maneuver were to occur, the trajectory of the Airbus 380 and the large wake turbulence produced by the Airbus 380 would combine with the winds aloft to drift the turbulence directly into the departure path of the ERJ-140. Agent 4 predicted the position of the ERJ-140 in relation to the wake turbulence and calculated that the turbulence would pose a significant threat to the low-energy state of the ERJ approximately 15 seconds after it became airborne. Agent 5 recognized that takeoff was imminent for the ERJ-140. As a result, the network of artificially intelligent agents predicted that there was a high probability of the ERJ-140 flying into the turbulence and losing control of the aircraft, resulting in an accident. Therefore, the safety network immediately produced an alert that recommended the

cancellation of the takeoff clearance for the ERJ-140. In other words, the super-intelligent network predicted an accident and intervened at just the right moment to prevent disaster.

It may be that in the previous example that the pilots of the A-380 decide the wind shear is not too severe and end up landing instead of going around. In that case, the cancellation of the takeoff clearance for the ERJ-140 would be seen as an inefficiency of the predictive intelligence. Perhaps the network would detect that the Airbus 380 was continuing to land, instead of going around, and would quickly rescind the ERJ-140's safety alert. In such a case the network could be queried for an explanation as to why the alert had been issued, if the flight crew or controller wanted to know. It is important to note that the machine learning capabilities of each agent would be extremely high and, therefore, each agent would learn from each and every "false alert" in order to continuously improve the accuracy of its predictive algorithms. Essentially, we are describing a constant learning safety network comprised of artificially intelligent agents.

It should also be noted that an adjustment to the accident probability alerting threshold would directly affect the number of false alerts. In the example, a threshold set at 50% may have prompted the safety alert when the network noticed that the air traffic controller was looking at the ERJ-140 holding short of the runway and detected the controller reaching for the push-to-talk switch, anticipating a takeoff clearance. In the same scenario, a threshold set at 75% may result in a safety alert just after the takeoff clearance is issued, as happened in the provided scenario. Or, a threshold set at 90% may have (a) delayed the alerting until after the takeoff roll of the ERJ-140 was initiated, then calling for a rejected takeoff if the ERJ-140 was still on the runway or (b) called for an evasive maneuver if the ERJ-140 was already airborne.

No human or team of humans could ever combine all the interrelated factors in the previous example with sufficient insight and speed to produce a safety alert, much less with any semblance of accuracy. Yet such a combination of factors is precisely how aviation accidents are caused. A networked system of machine intelligences could quickly and accurately determine when a dangerous confluence of factors start aligning and then produce an alert at a present probabilistic threshold that prevents the loss of control due to the wake turbulence encounter.

Although some experts claim that the time is coming when fully automated commercial aircraft, with no onboard pilots, will be the standard means of conveyance, before that day arrives, intelligent machines may virtually eliminate accidents in the same way that scientists have eliminated certain diseases.

CONCLUSION

The future certainly is difficult to predict, but we are able to extrapolate from emerging trends to explore probable upcoming developments in commercial aviation safety. We can say with certainty that airspace will be increasingly congested due to increases in traditional commercial air traffic and also due to new types of users of the airspace, such as UAS and suborbital space vehicles. There will likely be solutions adopted for the challenges of tracking aircraft operating in remote parts of the planet, such as oceanic airspace, and thus airliners will no longer go missing without a trace.

Aircraft themselves will be designed with enhanced safety and security systems. Similarly, increased defenses will be provided to counter some of the shortcomings of humans, such as the threat of lasers to our vision and life stresses that can produce poor psychological fitness for duty.

The science of safety management will also continue to evolve in sophistication, paired with a new generation of the most highly educated safety professionals in history. It is particularly interesting to contemplate a future for commercial aviation safety where artificial intelligence and SMS risk mitigation techniques combine to ensure a seamless safety value chain.

When taken together, all such developments will continue making commercial air travel the safest form of public transportation, which will be expected by an increasingly demanding public that is intolerant of accidents and serious incidents.

KEY TERMS

Accident Probability Alerting Threshold
Aircraft Communications Addressing and Reporting System (ACARS)
Artificially Intelligent Agents
Automatic Dependent Surveillance—Broadcast (ADS-B)
Bureau d’Enquêtes et d’Analyses pour la sécurité de l’aviation civile (BEA)
European Aviation Safety Agency (EASA)
Flight Operations Quality Assurance (FOQA)
Future Air Navigation System (FANS)
Global Aeronautical Distress and Safety System (GADSS)
Health Insurance Portability and Accountability Act (HIPAA)
International Federation of Air Line Pilots’ Associations (IFALPA)
Know Before You Fly

Know Before You Fly
Line Operations Safety Audits (LOSA)
NextGen
No Drone Zone
Predictive Safety
Proactive Safety
Psychological Fitness for Duty
Reactive Safety
Required Navigation Performance (RNP)
Space and Air Traffic Management System (SATMS)
Space Transition Corridors (STCs)
Unmanned Aircraft System (UAS)
Weather Support to Deicing Decision Making (WSDDM)

REVIEW QUESTIONS

1. How do commercial aircraft flight crew know what minimum altitudes must be flown in order to address threats posed by surface to air missiles?
2. Explain the potential hazards presented by UAS in today's airspace.
3. Explain why it is so hard to prevent illegal UAS operations.
4. Will integrating commercial space operations into the current air traffic control system increase the workload on controllers? Why or why not?
5. List three challenges associated with oceanic tracking.
6. Describe one emerging technology available for deicing planes on the ground.
7. Is it too harsh to charge a civilian with a felony for pointing a laser up at a plane? Discuss your response.
8. Differentiate between physiological and psychological fitness for duty. Is it more important to screen for physiological or psychological fitness for duty? Or should they be given equal consideration?
9. What are the potential benefits and drawbacks associated with requiring doctors to report pilot psychological problems?
10. If you were a safety management system manager who was given an extra $500,000 to invest, would you choose to invest it in hazard identification and analysis or training competencies? What is your rationale for deciding to invest where you did? How do you think this will affect the overall safety

management system?

11. What are some topics from this chapter that you would be interested in exploring if you were to pursue an aviation-related Ph.D. or Av.D degree? Why do you think your choices merit additional research?
12. Provide a specific example of how a future warning system based on artificial intelligence may prevent an accident.

SUGGESTED READING

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Regulator in the United States: http://www.faa.gov

Sample aviation doctoral program: http://www.cranfield.ac.uk
Sample aviation doctoral program: http://www.erau.edu
Sample aviation doctoral program: http://www.fit.edu
The state of artificial intelligence: https://www.youtube.com/watch?v=VBceREwF7SA
Transportation safety investigations in the United States: http://www.ntsb.gov

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